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ABSTRACT

This operations manual represents a continuation of operator training manuals developed for the United States Environmental Protection Agency (USEPA) in response to the technological advancements of wastewater treatment and the changing needs of the operations profession. It is intended to be used as a home-study course manual (using the concepts of self-paced instruction) or as a textbook for college and university courses. It contains chapters on: (1) odor control; (2) activated sludge; (3) solids handling and disposal; (4) solids removal from secondary effluents; (5) phosphorus removal; (6) nitrogen removal; (7) wastewater reclamation; and (8) instrumentation. Each chapter contains textual information, discussion and review questions, suggested answers, and an objective test. Included in the appendix are a final examination, tips on solving industrial waste arithmetic problems, a glossary of terms, and an index. (TW)

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A FIELD STUDY TRAINING PROGRAM

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ADVANCED WASTE TREATMENT

A Field Study Training Program

prepared by

California State University, Sacramento
(formerly Sacramento State College)
Department of Civil Engineering

in cooperation with the

California Water Pollution Control Association

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1987

OPERATOR TRAINING MANUALS

OPERATOR TRAINING MANUALS IN THIS SERIES are available from Ken Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-2654, phone (916) 278-6142.

1. *OPERATION OF WASTEWATER TREATMENT PLANTS*, 2 Volumes,
2. *OPERATION AND MAINTENANCE OF WASTEWATER COLLECTION SYSTEMS*, 2 Volumes,
3. *INDUSTRIAL WASTE TREATMENT*,
4. *TREATMENT OF METAL WASTESTREAMS*,
5. *PRETREATMENT FACILITY INSPECTION*,
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7. *SMALL WATER SYSTEM OPERATION AND MAINTENANCE*, AND
8. *WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE*.

NOTICE

This manual is revised and updated before each printing based on comments from persons using the manual.

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PREFACE TO THE FIRST EDITION
OF
ADVANCED WASTE TREATMENT

This operations manual is a continuation of the evolution of operator training manuals developed for the US Environmental Protection Agency by California State University, Sacramento, and the California Water Pollution Control Association. As the technology of wastewater treatment advances and the training needs of the operations profession changes, we strive to keep our training programs current.

An analysis of the subject matter and the users of *OPERATION OF WASTEWATER TREATMENT PLANTS*, Volume III, revealed two distinct categories of operators using this manual to meet their training needs and to serve as an operations, maintenance and troubleshooting reference. Operators of advanced wastewater treatment plants (tertiary facilities) need a training program that covers biological treatment processes as well as physical-chemical treatment processes. Operators of industrial wastewater treatment plants have similar needs, but with a different emphasis. One could argue that both groups should be served by a single manual or that two separate manuals could better serve the operations profession. If two separate manuals were to be prepared, how could the subject matter be appropriately divided and/or duplicated in each training manual?

We have accepted this challenge and have prepared two new manuals, (1) *ADVANCED WASTE TREATMENT* and (2) *INDUSTRIAL WASTE TREATMENT*. *ADVANCED WASTE TREATMENT* covers the topics of odor control, activated sludge, solids handling and disposal, solids removal from secondary effluents, phosphorus removal, nitrogen removal, wastewater reclamation and instrumentation. *INDUSTRIAL WASTE TREATMENT* covers the importance and responsibility of an industrial wastewater treatment plant operator. Other topics include the activated sludge process, physical-chemical treatment, instrumentation, industrial waste monitoring, industrial waste treatment and maintenance.

Whenever California State University, Sacramento, reprints one of our operator training manuals, the material is updated in accordance with the comments and suggestions received from the operators enrolling in the courses which use the manual. While you are reading the material in this Manual, please make notes of questions and areas where you would improve the material. By sending your comments and suggestions to me, operators who use the manual in the future will benefit from your knowledge and experience. Thanks.

1987

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CHAPTER 1

ODOR CONTROL

by

Tom Ikesaki

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OBJECTIVES

Chapter 1. ODOR CONTROL

Following completion of Chapter 1, you should be able to do the following:

1. Determine the source and cause of odors,
2. Respond to odor complaints, and
3. Solve odor problems.

GLOSSARY

Chapter 1. ODOR CONTROL

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ADSORPTION (add-SORP-shun) ADSORPTION

The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another substance.

BENZENE BENZENE

An aromatic hydrocarbon (C_6H_6) which is a colorless, volatile, flammable liquid. Benzene is obtained chiefly from coal tar and is used as a solvent for resins and fats and in the manufacture of dyes.

ELECTROLYTE (ELECT-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC PROCESS (ELECT-tro-LIT-ick) ELECTROLYTIC PROCESS

A process that causes the decomposition of a chemical compound by the use of electricity.

INDOLE (IN-dole) INDOLE

An organic compound (C_8H_7N) containing nitrogen which has an ammonia odor.

MERCAPTANS (mer-CAP-tans) MERCAPTANS

Compounds containing sulfur which have an extremely offensive skunk odor.

ODOR PANEL ODOR PANEL

A group of people used to measure odors.

OLFACTOMETER (ol-FACK-tom-meter) OLFACTOMETER

A device used to measure odors in the field by diluting odors with odor-free air.

OXIDATION (ox-i-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant) and used as a qualitative measure of the state of oxidation in wastewater treatment systems.

OXIDIZED ORGANICS OXIDIZED ORGANICS

Organic materials that have been broken down in a biological process. Examples of these materials are carbohydrates and proteins that are broken down to simple sugars.

OZONATION (O-zoe-NAY-shun) OZONATION

The application of ozone to water, wastewater, or air, generally for the purposes of disinfection or odor control.

PHENOL (FEE-noll) PHENOL

An organic compound that is a derivative of benzene.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions in wastewater, sulfate compounds or elemental suflur are reduced to odor-producing hydrogen sulfide (H_2S) or the sulfide ion (S^{-2}). The opposite of OXIDATION.

SKATOLE (SKATE-tole) SKATOLE

An organic compound (C_9H_9N) containing nitrogen which has a fecal odor.

STRIPPED ODORS STRIPPED ODORS

Odors that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed and/or tumbled over media.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a sample (gas or water) that can just be detected after successive odorless (gas or water) dilutions.

CHAPTER 1. ODOR CONTROL

1.0 NEED FOR ODOR CONTROL

Odor control in wastewater collection systems and at wastewater treatment plants is becoming very important. With the increased demand for housing, collection systems are being extended farther and farther away from the treatment plant. Longer collection systems create longer flow times to reach the treatment plant. Increased travel times cause the wastewater to become septic and thus cause odor and corrosion problems in collection systems and treatment plants. To complicate matters the larger buffer areas around wastewater treatment plants have all but disappeared. Land values and increased population have made it impossible to continue to have large buffer areas around most plants. As homes and businesses become neighbors to existing plants, what was a minor odor problem now becomes a major problem. No longer can even the smallest trace of odor exist without complaints from neighbors. Thus, preventing the emission of odors has become a prime operating consideration.

1.1 ODOR GENERATION

In order to control odors more effectively, an understanding of odor generation is needed. Understanding the problem and the causes will lead to a more effective solution.

1.10 Biological Generation of Odors

The principal source of odor generation is a result of the production of inorganic (no or one carbon in formula, H_2S) and organic (more than one carbon in formula, C_8H_7N) gases by microorganisms in the collection system and treatment processes. Odors also may be produced when odor-containing or odor-generating materials are discharged into the collection system by industries and businesses.

The main concerns of operators are the inorganic gases HYDROGEN SULFIDE (H_2S) and AMMONIA (NH_3). These two gases give off the most offensive odors. As little as 0.5 ppb (parts of gas per billion parts of air) of either of these gases can be detected by the human nose and cause odor complaints. Hydrogen sulfide has an extremely offensive smell and has the odor produced by rotten eggs. Ammonia has a very sharp, pungent smell and also is very offensive. Other inorganic gases found in wastewater treatment plants are: carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), oxygen (O_2), and hydrogen (H_2). Normally found in nature, these gases are the products of normal respiration and biological activity of plants and animals and are not odorous.

Organic gases usually are formed in the collection system and in the treatment plant by the anaerobic decomposition of nitrogen and sulfur compounds. Organic gases also can derive their odors from industrial sources. Examples of organic gases found around treatment plants are *MERCAPTANS,*[1] *INDOLE,*[2] and *SKATOLE.*[3] These odorous compounds contain nitrogen- and sulfur-bearing organic compounds.

In the normal biological oxidation of organic matter, the microorganisms remove hydrogen atoms from the organic compounds. In the process, the microorganisms use the bound sources of oxygen to gain energy. The hydrogen atoms are then transferred through a series of reactions that are sometimes called "hydrogen transfer" or "dehydrogenation."

1.11 Hydrogen Transfer Schemes

The following reactions illustrate the role of the hydrogen atom in the formation of both odorless and odorous compounds or end products.

Hydrogen Acceptor		Hydrogen Atoms Added		End Product
AEROBIC REACTION				
O_2 Molecular Oxygen	+	$4 H^+$	→	$2 H_2O$ Water (Odorless)
ANAEROBIC REACTIONS				
$2 NO_3^{-1}$ Nitrate	+	$12 H^+$	→	$N_2 + 6 H_2O$ Nitrogen Gas (Odorless)
CO_2 Carbon Dioxide	+	$8 H^+$	→	$CH_4 + H_2O$ Methane Gas (Relatively odorless)
SO_4^{-2} Sulfate	+	$10 H^+$	→	$H_2S + 4 H_2O$ Hydrogen Sulfide Gas (Odorous)
Oxidized Organics[4]	+	n H^+	→	Lower Organics (Odorous)

The order in which microorganisms break down compounds containing oxygen in nature is: molecular oxygen (free dissolved oxygen), nitrate, sulfate, oxidized organics, and carbon dioxide.

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[1] *Mercaptans (mer-CAP-tans). Compounds containing sulfur which have an extremely offensive skunk odor.*

[2] *Indole (IN-dole). An organic compound (C_8H_7N) containing nitrogen which has an ammonia odor.*

[3] *Skatole (SKATE-tole). An organic compound (C_9H_9N) containing nitrogen which has a fecal odor.*

[4] *Oxidized Organics. Organic materials that have been broken down in a biological process. Examples of these materials are carbohydrates and proteins that are broken down to simple sugars.*

There are some organisms that can only use molecular oxygen and cannot use the other forms. These microorganisms are called "strictly aerobic microorganisms." "Facultative microorganisms" can use molecular oxygen and combined (or bound) sources of oxygen such as nitrate. Still others, "strictly anaerobic microorganisms," can only use bound sources such as nitrate.

DEHYDROGENATION

1.12 Hydrogen Sulfide Generation

The main cause of most odors in wastewater systems is hydrogen sulfide. Hydrogen sulfide can be detected by the human nose in very low concentrations. This gas has a very characteristic rotten egg odor. The conditions which lead to hydrogen sulfide production also are conditions which produce other odors and other problems. These problems include dangers from explosive gas mixtures and hazards to the respiratory system to persons working in confined or close spaces and corrosion or deterioration of concrete sewer structures (such as pipelines and manholes). For these reasons, special attention is given to hydrogen sulfide generation.

The most common source of sulfide in wastewater is biological activity in the collection sewer or treatment plant. Sulfide compounds can develop in the natural breakdown of sulfur-bearing organic compounds. The source for the breakdown is protein that is discharged in wastes in the forms of undigested amino acids as part of feces and in urine as part of the unstable urea protein. This natural breakdown accounts for only a minor portion of all the sulfide compounds in the system. The major part of odor-producing sulfide results from the breakdown of inorganic sulfur compounds.

The principal sulfur compound found in wastewaters is sulfate. Sulfate compounds find their way into wastewaters from the public water supply and from industrial sources. The presence or absence of oxygen establishes whether or not hydrogen sulfide will exist. When dissolved oxygen is present, the sulfate ions will remain as sulfate. If the wastewater does not contain dissolved oxygen, the biological breakdown will reduce sulfate to sulfide, using the oxygen in the sulfate compound for energy to break down organic matter. Although sulfate and all essential elements may be present, sulfide is not produced in all wastewater systems. The pH of the wastewater is an important condition. Hydrogen sulfide is extremely pH dependent. Sulfide can exist in wastewater in three forms depending on the pH: S^{-2} ion, HS^- ion, or H_2S gas. When sulfide is in an ionic form, it is in solution so that it cannot escape as a gas. Odors are formed and released when sulfide is in the gaseous form (H_2S). The pH of the solution has to be below pH 7.5 in order for hydrogen sulfide gas to escape. At a pH below 5, all sulfide is present in the gaseous H_2S form and most of it can be released from wastewater to cause odor, corrosion, explosive conditions and respiratory problems.

SULFIDE FORMS (also see Fig. 1.1)

hydrogen sulfide (H_2S) gas	H_2S, 50% HS^-, 50%	HS^- ion 100%	S^{-2} ion 100%
below pH of 5	neutral pH of 7	pH of 9	above pH of 10

The temperature of the system is an important factor that must be considered, because the rate of bacterial metabolism is related to temperature. Areas where the temperature is normally above 65°F (18°C) have more problems than those with lower temperatures. Hydrogen sulfide generation is the greatest at temperatures around 85°F (30°C) and above.

Figure 1.2 shows the sulfur cycle. The arrows indicate all the ways sulfide can be produced in collection systems and treatment plants.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 28.

1.0A Why is wastewater tending to become more septic and thus causing odor and corrosion problems?

1.1A How are odors produced?

1.1B What are the main inorganic gases of concern to operators?

1.1C What is the order in which microorganisms break down compounds containing oxygen in nature?

1.1D What is the major source of inorganic odor-producing sulfate compounds found in collection systems and treatment plants?

1.1E Hydrogen sulfide causes problems at what pH range?

1.2 ODOR IDENTIFICATION AND MEASUREMENT

In order to control odors effectively, the operator should know where odors originate and the cause. Odor detection in the past has been very unscientific because it relied on the human sense of smell. While our noses are more sensitive than most instruments or detection devices, each person has a different tolerance level for various odors. Occasionally what smells good to one individual smells bad to another.

Odors can be detected by the use of lead-acetate strips to reveal the presence of hydrogen sulfide. Gas detection devices can be used to detect the presence of specific gases that cause odors. Today odors can be measured by the use of an *OLFACTOMETER*[5] or an *ODOR PANEL.*[6] The olfactometer can measure odors in the field by diluting the odors with odor-

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[5] *Olfactometer (ol-FACK-tom-meter). A device used to measure odors in the field by diluting odors with odor-free air. Reference, Metcalf & Eddy, Inc.,* WASTEWATER ENGINEERING TREATMENT, DISPOSAL, REUSE, *McGraw-Hill, New York, 1979.*

[6] *Odor Panel. A group of people used to measure odors. Procedures for measuring odors by the use of a group of people are designated D1391-57 by the American Society for Testing Materials, Philadelphia, Pennsylvania.*

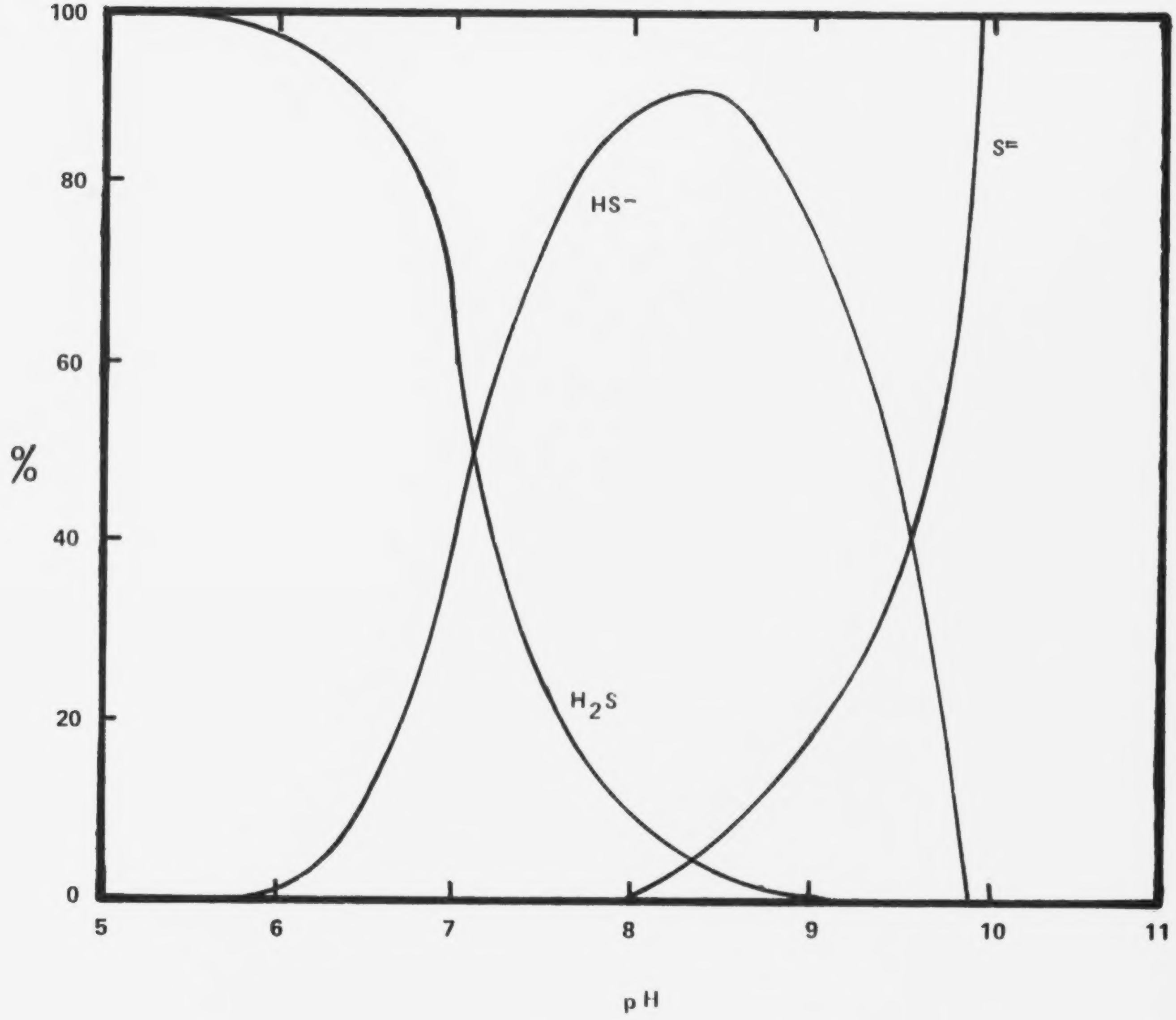


Fig. 1.1 Effect of pH on hydrogen sulfide-sulfide equilibrium

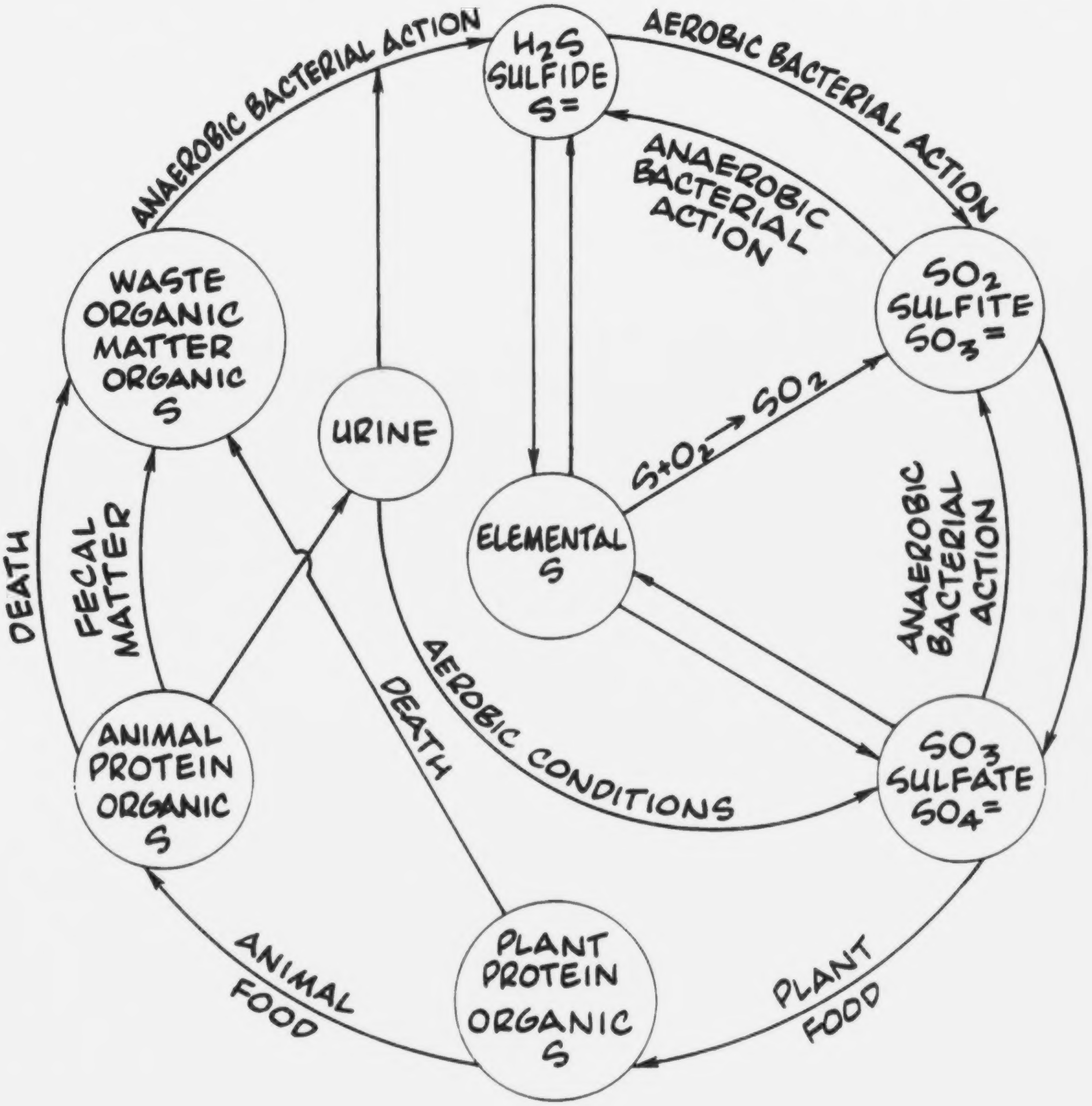

H₂S
SULFIDE
S=
AEROBIC BACTERIAL ACTION
ANAEROBIC BACTERIAL ACTION
ANAEROBIC BACTERIAL ACTION
SO₂
SULFITE
SO₃=
WASTE ORGANIC MATTER ORGANIC S
URINE
S+O₂ → SO₂
ELEMENTAL S
ANAEROBIC BACTERIAL ACTION
O₂
DEATH
FECAL MATTER
DEATH
AEROBIC CONDITIONS
ANIMAL PROTEIN ORGANIC S
SO₃
SULFATE
SO₄=
PLANT PROTEIN ORGANIC S
ANIMAL FOOD
PLANT FOOD

Fig. 1.2 Sulfur cycle

free air. The number of dilutions required to reduce an odor to its minimum *THRESHOLD ODOR*[7] concentration provides a quantitative measure of the concentration of strength of an odor. The results are reproducible within reasonable levels.

Certain types of odors have significant effects on people and animals. These odors have a major health and economic impact on those affected. For these reasons, the identification of odors is important. Once the odor has been identified, the solutions can be studied. Unfortunately for us, different noses are sensitive to different odors and the sensitivity of individual noses varies from day to day.

The following are some facts that can help in odor classification:

1. All individuals have a sense of smell,
2. Individuals respond differently to the same odor,
3. Some odors are objectionable and others are pleasant,
4. Odors travel great distances with the direction of the wind,
5. Small concentrations of odors can be offensive,
6. Similar compounds do not have the same odor, and
7. The human nose rapidly becomes fatigued (insensitive) to odors.

The best that most operators can do when recording odors is to classify the odor in some reasonable fashion. Sometimes a person not working in a plant will have to identify odors because an operator's nose can become insensitive. Usually the smells or odors can be classified into the following groups:

Skunk,
Rotten cabbage,
Ammonia,
Fecal,
Rotten egg, and
Decayed flesh.

With this information the operator can begin attacking the source of the problem. Skunk odors are frequently organic gases that contain sulfur compounds. These odors are usually from mercaptans. Rotten cabbage odors come from organic compounds with sulfur compounds attached. Usually the organic compound associated with this smell is dimethyl sulfide. Fishy smells are organic compounds that have nitrogen compounds attached. Dimethyl amine is a typical compound producing such a smell. Ammonia odors come from organic compounds with nitrogen attached. Indole is such a compound. Fecal odors are derived from skatole, which is an organic compound with nitrogen attached. Rotten egg odors are from the hydrogen sulfide molecule. The smell of decayed flesh comes from diamines which are another ammonia-type compound.

All of these compounds are similar, but they all smell different. Once the odors are identified, the source may be controlled and possibly eliminated. Solutions to odor problems are different if there are mixtures of odors because different compounds are involved.

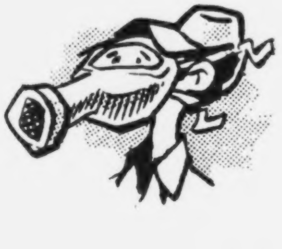
Table 1.1 summarizes the odors we can detect from various substances and the threshold odor concentration, the level at which our nose first detects an odor.

TABLE 1.1 ODOR CHARACTERISTICS[a]

SUBSTANCE	REMARKS	TYPICAL[b] THRESHOLD ODOR, ppm
ALKYL MERCAPTAN	VERY DISAGREEABLE, GARLIC-LIKE	0.00005
AMMONIA	SHARP, PUNGENT	0.037
BENZYL MERCAPTAN	UNPLEASANT	0.00019
CHLORINE	PUNGENT, IRRITATING	0.010
CHLOROPHENOL	MEDICINAL	0.00018
CROTYL MERCAPTAN	SKUNK	0.000029
DIPHENYL SULFIDE	UNPLEASANT	0.000048
ETHYL MERCAPTAN	ODOR OF DECAYED CABBAGE	0.00019
ETHYL SULFIDE	NAUSEATING	0.00025
HYDROGEN SULFIDE	ROTTEN EGG	0.0011
METHYL MERCAPTAN	DECAYED CABBAGE	0.0011
METHYL SULFIDE	DECAYED VEGETABLE	0.0011
PYRIDINE	DISAGREEABLE, IRRITATING	0.0037
SKATOLE	FECAL, NAUSEATING	0.0012
SULFUR DIOXIDE	PUNGENT, IRRITATING	0.009
THIOCRESOL	RANCID, SKUNK-LIKE	0.0001
THIOPHENOL	PUTRID	0.000062

[a] *MOP 11*, Chapter 27, "Odor Control," Water Pollution Federation, Washington, D.C., 1976.

[b] Various references will list slightly different threshold odor concentrations.



1.3 ODOR COMPLAINTS

Periodically all wastewater treatment plants will cause some odor. These will be detected by the public and must be handled by the operator. All complaints should be answered promptly and courteously. The public pays for your services and indirectly is your boss.

NEVER APPROACH A HOME WITH A NEGATIVE ATTITUDE.

Beginning a conversation with a negative attitude will quickly upset the public. Even if you can't detect the odor when you answer a complaint, that does not mean that the odor was not there or is not there now. Your nose may not be as sensitive as the nose of the person filing the complaint. Also, your nose may be accustomed to the smell and no longer be able to detect the offensive odor.

The greatest complication develops if you do not properly handle the problem. If the public unites against the plant and becomes very odor conscious, even the slightest odor can cause an uproar. Remember that the person filing the complaint called because of a problem. You must be a diplomatic listener. Invite those who have complained to visit the plant and offer them a tour. While you are showing them around the plant, they may indicate to you where the odor that is bothering them is the strongest. This information may help you identify and control the cause of the odor problem.

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[7] ***Threshold Odor.** The minimum odor of a sample (gas or water) that can just be detected after successive odorless (gas or water) dilutions.*

Whenever an odor complaint is investigated, a record should be made of the visit and the important facts recorded (Fig. 1.3). Investigations in the neighborhood near the location of an odor complaint can be very helpful. Odors can be coming from a nearby sewer, storm drain, trash pile, home plumbing problem, or dead animal. If an odor complaint is repeated and the source cannot be located, consider sending personnel to the site during the time of day when odors are a problem to determine the source.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 28.

1.2A How can odors be measured?

1.2B List as many groups or types of odors or smells as you can recall.

1.3A Never approach a person who has an odor complaint with a ________ attitude.

1.3B When investigating an odor complaint, why might you be unable to detect an odor that is disturbing to the person complaining?

1.4 SOLUTIONS TO ODOR PROBLEMS

In order to solve any odor problem, a good systematic problem analysis is essential. The following steps indicate the procedure to follow when attempting to solve odor problems.

1. Make an on-site inspection and investigation of the problem areas.
2. Attempt to identify the source or cause of the problem.
3. Review plant housekeeping.
4. Review plant operations.
5. Review plant performance.
6. Evaluate plant performance.
7. Review engineering or design features of the plant.
8. List and review all solutions to the problem.
9. Put into practice the best possible solution.

Solving the problem may create complications including new odors and operating problems. Many times the odor is produced by a number of different gases in combination. When this happens, a single solution may not be the answer. Chemicals which counter the highest odor may cause other odors which are even more offensive. Solutions to odor problems may substantially increase operating and chemical costs. Often the solution will not be a textbook answer, but a combination of solutions developed by trial and error and technical aid from others.

To solve odor problems, try to identify the source and correct the problem when the odors are being produced. Solutions consist of preventing the development of anaerobic conditions and/or retarding or stopping the activity of organisms which produce odors under anaerobic conditions.

1.40 Chemical Treatment of Odors in Wastewater

1.400 Chlorination

Chlorination is one of the oldest and most effective methods used for odor control. Chlorine is used in the disinfection process and is readily available at the wastewater treatment plant. Because of this availability, chlorine is frequently used to control odors. Chlorine is a very reactive chemical and, therefore, oxidizes many compounds in wastewater. The reaction between chlorine and hydrogen sulfide and ammonia has been studied by many researchers.

The reaction between chlorine and hydrogen sulfide is:

$$H_2S + 4\,Cl_2 + 4\,H_2O \rightarrow H_2SO_4 + 8\,HCl$$

The reaction of ammonia with chlorine is:

$NH_3 + Cl_2 \rightarrow NH_2Cl + HCl$ (monochloramine, NH_2Cl)

$NH_2Cl + Cl_2 \rightarrow NHCl_2 + HCl$ (dichloramine, $NHCl_2$)

$NHCl_2 + Cl_2 \rightarrow NCl_3 + HCl$ (trichloramine, NCl_3)

The most important role that chlorine plays in controlling odors is to inhibit the growth of odor-causing microorganisms. This control requires less chemical than trying to oxidize the odor once formed. This means that the chlorine should be added in the collection system ahead of the plant.

Odors are not always removed by the use of chlorine. The reaction of chlorine with certain chemicals can cause a more odorous gas. One example is the reaction of chlorine with *PHENOL*[8] to form chlorophenol, a medicinal-smelling substance.

Sodium hypochlorite has been used like chlorine to control odors. The chemical reactions with other substances are very similar.

Experience has shown that a 12 to 1 dose of chlorine to dissolved sulfide (12 mg/*L* chlorine per each 1 mg/*L* sulfide) is needed to control the generation of hydrogen sulfide in sewers. Do not determine the chlorine dose on the basis of the concentration of H_2S in the sewer atmosphere.

1.401 Hydrogen Peroxide

For a number of years, hydrogen peroxide (H_2O_2) has been used as an oxidant to control odors. Hydrogen peroxide reacts in three possible ways to control odors.

1. Oxidant action:	Oxidizes the compound to a nonodorous state. An example of this is the conversion of hydrogen sulfide to sulfate compounds. $H_2S + H_2O_2 \rightarrow H_2O$ + sulfate compounds In actual practice a dose of 2:1 to 4:1 of H_2O_2 to S^{-2} is needed for control.
2. Oxygen producing:	Acts to prevent the formation of odor compounds. This is accomplished by keeping the system aerobic.
3. Bactericidal to the sulfate-reducing bacteria:	Kills the bacteria that produce odors. Without biological activity, odors will not be generated. This high a dose of H_2O_2 is probably not economically feasible.

---

[8] *Phenol (FEE-noll). An organic compound that is a derivative of benzene.*

Date ____________________ Name of investigator ____________________

Location ____________________

Person filing complaint ____________________

Address ____________________

Phone number ____________________

Date and time complaint occurred ____________________

Nature of complaint ____________________

____

INVESTIGATION:

Date and time of investigation ____________________

Strength of odor

1. ____ No odor
2. ____ Faint
3. ____ Noticeable
4. ____ Definite
5. ____ Strong
6. ____ Overwhelmingly strong

Description of odor

1. ____ Ammonia
2. ____ Decayed Cabbage
3. ____ Fecal
4. ____ Fishy
5. ____ Garlic
6. ____ Medicinal
7. ____ Rotten Egg
8. ____ Skunk
9. ____ Other

Wind direction

1. ____ North wind
2. ____ South wind
3. ____ East wind
4. ____ West wind
5. ____ No wind

Strength of wind

1. ____ Quiet
2. ____ Mild
3. ____ Gusty
4. ____ Strong
5. ____ Very strong

Try to comment on whether odor occurs during any specific time of the day, day of the week, or weather conditions.

Comments: ____________________

____

____

____

Reviewed by: ____________________ Date ____________

(Chief Operator)

Corrective Action: ____________________

____

____

____

Fig. 1.3 Odor complaint form

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 28.

1.4A Outline the systematic steps you would follow to solve an odor problem.

1.4B What is the most important role that chlorine plays in controlling odors?

1.4C What are the three possible ways hydrogen peroxide reacts to control odors?

1.402 Oxygen

Oxygen has been used with a great deal of success. The most common practice with oxygen is to use air to aerate the wastewater and try to keep the wastewater aerobic. The transfer of oxygen to the wastewater will increase its *OXIDATION-REDUCTION POTENTIAL*[9] (ORP) and thus reduce the formation of odorous gases. With increased ORP, the sulfate ion is not used as an oxygen source, so the odor is reduced.

Up-stream aeration will cause hydrogen sulfide to be stripped out (carried out by the air) of the liquid, if it is present, and thus reduce the release of odors at the plant when water flows over weirs or other locations of high turbulence. *STRIPPED ODORS*[10] may be collected from above the surface where aeration takes place and be treated. If these odors are not properly handled, localized corrosion and odor problems can result.

1.403 Ozone

Ozone is a powerful oxidizing agent that effectively removes odors. Ozone has limited use because an effective concentration may be too costly to use at large treatment plants. Ozone works well when used to remove odors from air collected over sources of odors (Section 1.48).

An advantage of ozone is the fact that there are no known deaths resulting from the use of ozone. Ozone can cause irritation of your nose and throat at a concentration of 0.1 ppm, but your nose can smell ozone around 0.01 to 0.02 ppm. Another advantage of ozone is that you can manufacture what you need at the plant site and do not have to handle bulky containers. Ozone is not available in containers because it is relatively unstable and cannot be stored.

1.404 Chromate

Chromate compounds can effectively inhibit the sulfate reduction to sulfide. However, this method introduces heavy metals into the sludge and wastewater, and this may cause an even more offensive odor. Heavy metals, such as chromate, cause serious toxic conditions that limit their usefulness.

1.405 Metallic Ions

Certain metallic ions (mainly zinc) have been used to form precipitates with sulfide compounds. These precipitates are insoluble and have a toxic effect on biological processes such as sludge digestion. Therefore, this process has its limitations.

1.406 Nitrate Compounds

The first chemicals used in the anaerobic breakdown are nitrate ions. If enough nitrate ions are present, the sulfate ions will not be broken down. The cost of this type of treatment to halt hydrogen sulfide production is very high and, at present, is not practical.

1.407 pH Control (Continuous)

Increasing the pH of the wastewater is an effective odor control method for hydrogen sulfide. By increasing the pH above 9, biological slimes and sludge growth are inhibited. This, in turn, halts sulfide production. Also, any sulfide present will be in the form of the HS^- ion or S^{-2} ion, rather than as H_2S gas which is formed and released at low pH values.

1.408 pH Control (Shock Treatment)

Short term, high pH (greater than 12.5) slug dosing with sodium hydroxide (NaOH) is effective in controlling sulfide generation for periods of up to a month or more depending on temperature and sewer conditions. Care must be exercised in selecting the length of dosing so that downstream treatment plant biological systems will not be seriously impaired.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 28.

1.4D How is oxygen used to control odors?

1.4E What is a limitation of using metallic ions to precipitate sulfide?

1.4F How can pH adjustment control odors from hydrogen sulfide?

1.41 Biological Odor Reduction Towers (ORT) (Fig. 1.4)

An odor removal tower is essentially a deep bed trickling filter that is lightly loaded to produce a nitrifying biological zoogleal mass on the filter media. Foul air and off gases from the treatment plant process system are captured and piped into the bottom of the odor removal tower. As this odorous air passes up through the filter media, the odors may be oxidized to an acceptable odor level and discharged to the atmosphere at the top of the tower. The odor reduction tower (ORT) has two flow streams, one liquid to maintain the biomass on the media and also the air flow carrying the odors.

1.410 Odor Reduction Tower Parts

LIQUID STREAM

1. Filter Media. Usually plastic media is used to provide surface area for the biological slimes or biomass to attach themselves. The filter media bed depth may range from twenty to thirty feet (6 to 9 m) in depth.

---

[9] *Oxidation-Reduction Potential. The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant) and used as a qualitative measure of the state of oxidation in wastewater treatment systems.*

[10] *Stripped Odors. Odors that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed and/or tumbled over media.*

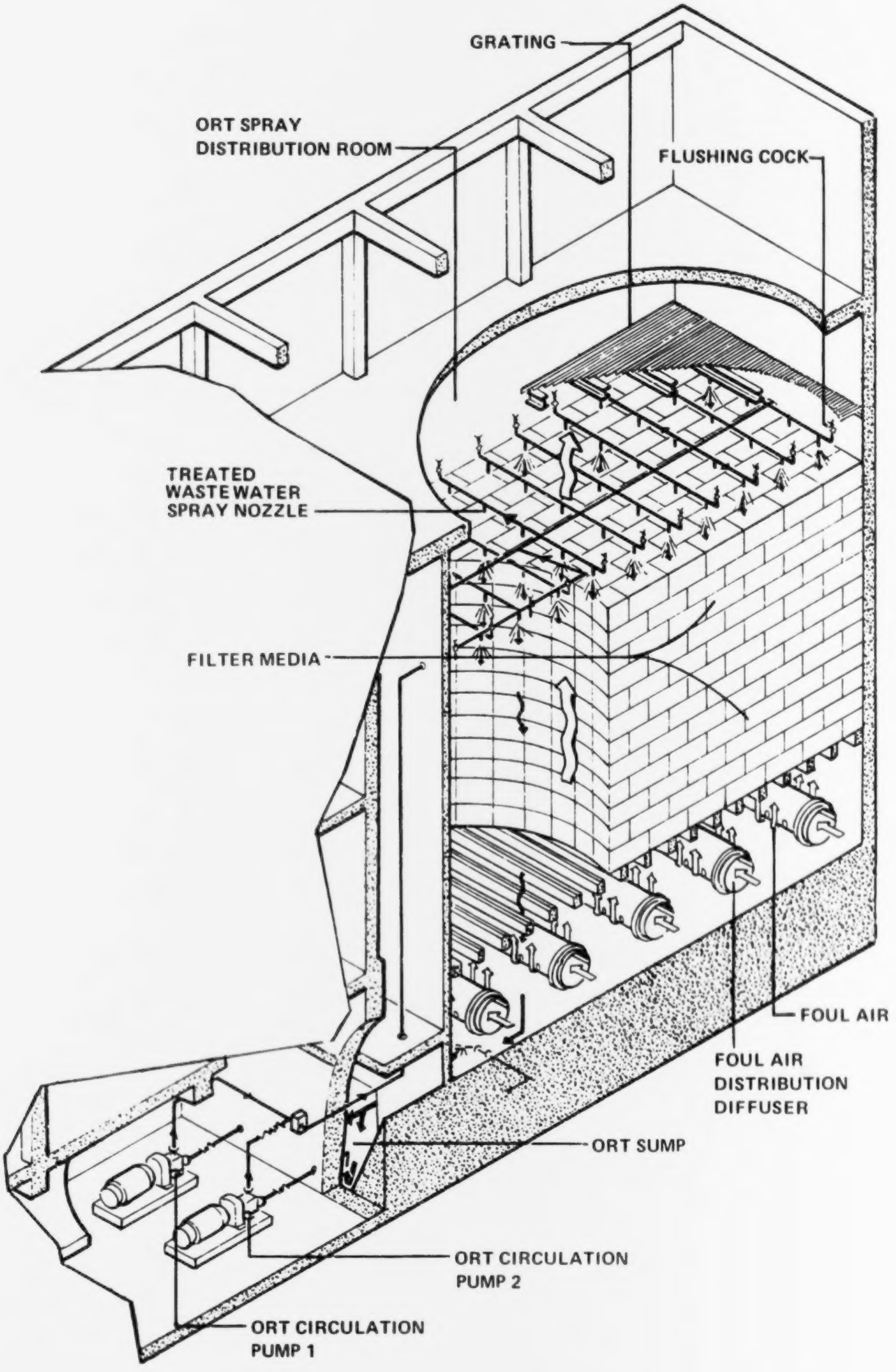
GRATING
ORT SPRAY DISTRIBUTION ROOM
FLUSHING COCK
TREATED WASTEWATER SPRAY NOZZLE
FILTER MEDIA
FOUL AIR
FOUL AIR DISTRIBUTION DIFFUSER
ORT SUMP
ORT CIRCULATION PUMP 2
ORT CIRCULATION PUMP 1

Fig. 1.4 Biological odor reduction tower (ORT)

(Permission of Sacramento Area Consultants)

2. Filter Sump. A tank at the bottom of the filter where the applied liquid (primary or secondary effluents) is collected to be pumped back over the filter media to sustain the biomass.

3. Sump Overflow. An outlet weir that prevents the filter sump from filling too high and returns the overflow back to the plant headworks.

4. Filter Feed Pump. A pump that recycles secondary effluent from the treatment plant to the top of the filter. This water is applied through spray nozzles to the filter bed. The filter feed may be secondary effluent or a blend of secondary and primary effluent. This blend is essential to maintain the proper BOD loading on the filter to support the biomass in a nitrifying stage.

5. Spray Nozzles. Nozzles placed over the top of the filter media to assure an even distribution over the filter of the recirculated effluent. These spray nozzles perform the same function as the rotating distributor arm on a trickling filter.

AIR STREAM

1. Supply Fans (Blowers). Fans that transport foul air and off gases from the treatment plant process units through ducts and pipes to diffusers at the bottom of the odor reduction tower.

2. Mist Eliminator. A device located at the top of the odor reduction tower above the filter bed. This device separates as much moisture as possible from the gas stream before it enters the exhaust fan of the odor reduction tower to be discharged to the atmosphere.

3. Tower Exhaust Fan. This fan pulls air from the filter bed and tower column and discharges scrubbed air to the atmosphere.

1.411 Odor Reduction Tower Loading Rates

Recommended loading rates to maintain a nitrifying biomass are summarized in Table 1.2. Odor reduction towers operated in accordance with Table 1.2 should use secondary effluent and a single pass operation. There are two advantages to this method of operation. One, plugging of the spray heads is minimized by using secondary rather than primary effluent. Two, a single pass operation prevents buildup of sulfuric acid (H_2SO_4) which could eventually corrode the structure and equipment. The pH must be maintained above 6.0. Caustic soda can be added to the feed water if necessary to increase the pH.

TABLE 1.2 ODOR REDUCTION TOWER LOADING RATES

Organic Loading	= 0.5 lbs BOD/day/cu yd media (0.3 kg BOD/day/cu m media)
Hydraulic Loading	= 2.3 to 3.0 GPM/sq ft media surface (1.6 to 2.0 *L*/sec/sq m media surface)
Foul Air Application	= 125 CFM/sq ft media surface (0.63 cu m air/sec/sq m media surface)
Average Air Velocity	= 150 ft/min (46 m/min)
Maximum Feed Water Recirculation	= 7:1

1.412 Start Up

1. Check to determine if all items such as hatches, grates, and duct work are secure.
2. Check sump for debris and dirt. Wash down the sump and inspect the overflow line.
3. Check filter spray heads for operation and position of flushing valves. Flushing valves should be closed.
4. Check drain lines from mist eliminators. They should be free of obstructions and the drain valves should be closed.
5. Inspect condition of supply and discharge fans. These fans should rotate freely and have the proper lubricants and belt tension.
6. Fill sump with effluent to the proper level. Regulate supply flow to the sump to make up for the small amount being returned to the plant through the overflow box.
7. Start recirculation pump which supplies water to the filter media sprinklers. Examine sprinkler operation and water distribution patterns on the top of the filter bed. Clean any nozzles that are plugged or restricted.
8. Start tower discharge and supply fans. Note that the tower will not remove odors from the gas stream until a biomass is established on the filter media. The fans do not have to run until the biomass is established. Some air must be ventilated through the filter bed during start up.

1.413 Odor Reduction Tower Monitoring

DAILY

1. Check operation of fans and pumps.
2. Drain mist eliminators.
3. Check for proper sump level and make up water feed supply.
4. Measure pH of sump feed recirculation water to the filter. Do not allow the pH to drop below 6.0. If the pH is too low, either increase the make up water addition rate (increase sump overflow rate) or raise pH by the addition of caustic soda. Water with a low pH can cause corrosion damage.

WEEKLY

1. Measure BOD loading across filter surface.
2. Check spray nozzle distribution pattern. The supply fan may have to be turned off during this check.
3. Lubricate fans and pumps.

QUARTERLY

1. Inspect sump for silt and debris. Supply fan and recirculation pump may have to be turned off during this inspection.

ANNUALLY

Take odor reduction tower out of service.

1. Check and clean spray nozzles and distribution lines.
2. Check air ducts, plenums, fan housings, diffusers and mist separators for corrosion. Clean and paint as required.
3. Clean sump.
4. Flush filter media. Inspect media for fit (secureness) and deterioration of media, grates, valves, and other appurtenances.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 29.

1.4G How are off gases and foul air treated in a biological odor reduction tower?

1.4H How is the filter feed spread over the media?

1.4I Why should the pH of the spray water not be allowed to drop below 6.0?

1.4J How can the pH of the spray water be increased if the pH becomes too low?

1.42 Treatment of Odors in Air

The practice of treating air containing odors from a treatment process may be more economical than treating the wastewater. This type of odor control is becoming more and more popular. The methods of controlling odors in air include masking and counteraction (counter masking), combustion, absorption, adsorption, and *OZONIZATION*.[11]

1.43 Masking, Modification and Counteraction

Odor masking has been used with limited success for many years. Odor masking is accomplished by taking the odorous compound and mixing it with a control agent. The masking agent or chemical has a stronger and supposedly more pleasant odor quality which, when mixed with the odorous compound, results in a more pleasant odor than the odorous compound.

"Counteraction" is the control of odors by adding nonodor-producing reactive chemicals to the odor by spraying the air over the odor-producing area.

Caution must be exercised when considering the application of masking chemicals because they are usually chlorinated *BENZENE*[12] compounds. These compounds may be undesirable from an environmental stand point.

1.44 Combustion

Industry has been removing odorous gases by combustion for years. The problem with using combustion to remove odors from a wastewater treatment plant is that the concentrations of odors in the gases are extremely low and the combustibility of the gases is so low that fuel costs are high.

The key to the process is temperature. It has been reported that the best temperature is greater than 1500°F (820°C). If insufficient temperatures are used and incomplete combustion occurs, odors that are not completely oxidized can be more obnoxious than the original odor.

1.45 Absorption

"Absorption" is the process in which the odorous components are removed from a gas by being taken in or soaked up by a chemical solution.

Odors may be absorbed through a process called "scrubbing." This process is one of the most economical methods used today. The odorous compound is absorbed into a solution, either through solubility or chemical absorption. Odors may be scrubbed with chemicals such as potassium permanganate, sodium hypochlorite, caustic soda, and chlorine dioxide.

The air stream must be brought into contact with the absorbing compound. Usually air is moved through ducts to a scrubbing unit. A scrubbing unit is a device that provides for the contact of the air and scrubbing compound. This device may be a simple spray chamber, packed tower, or any similar unit. Spray chambers usually are not as effective as other methods due to the short contact time. Contact time is achieved through the use of packed media towers or tray towers (Fig. 1.5).

Regardless of the chemical used, the arrangement of the units is very similar. Some of the odorous gases removed by a hypochlorite process are hydrogen sulfide, mercaptans, sulfur dioxide, ammonia, and organic gases. Absorption using this method (hypochlorite) is very rapid. Unfortunately, all odorous gases are not removed by this method or by the same chemicals.

A brine solution absorption system is shown in Figure 1.6. Salt is dissolved in water in the brine tank. This brine solution flows into the recycle tank. The solution is pumped from the recycle tank directly over the media or to electrolytic cells. As the brine solution passes through electrolytic cells oxidizing agents are formed and this solution is sprayed over the media. When this solution comes in contact with odorous gases as it flows over the media, the odorous gases are oxidized to form less objectionable gases. Odorous air may flow horizontally through the media (Fig. 1.5) or vertically through the media in a column. This system has been used successfully to reduce odors significantly from organically overloaded plastic-media trickling filters.

1.46 Chemical Scrubber Units for Foul Air Treatment

This absorption process removes odors from gases produced at various treatment processes and locations in a treatment plant. Odors are removed by *ELECTROLYTIC PROCESSES*[13] which generate oxidizers that destroy or convert odors into harmless, nonodorous gases. The system works very similar to the old radio-vacuum tubes by an anode-cathode assembly.

The anode-cathode assembly is the key in the scrubber system, and the heart of the assembly is the anode. Each assembly is activated when the rectifier transfers electrons from the anode (leaving it positively charged) and forces them on the cathode making it negatively charged. Raising the voltage causes an excess of electrons on the cathode to seek a means of reaching the electron deficient anode. Electrons on the cathode will use any available means to cross the gap between the two surfaces.

Should pure water fill the void between the anode and cathode, only a few electrons would escape to the anode. If, however, soluble salts are present, the conductivity of the water is immensely increased. As the electrons flow across the gap, they chemically convert the salt to sodium hypochlorite and disassociate some water into oxygen and hydrogen.

As the concentration of soluble salts increases, electron flow resistance diminishes. Subsequently, less voltage is required to force the transfer of electrons from the cathode to the anode; and the chemical changes occurring to the dissolved salts are increased.

---

[11] *Ozonization (O-zoe-nie-ZAY-shun). The application of ozone to water, wastewater, or air, generally for the purposes of disinfection or odor control.*

[12] *Benzene. An aromatic hydrocarbon (C_6H_6) which is a colorless, volatile, flammable liquid. Benzene is obtained chiefly from coal tar and is used as a solvent for resins and fats and in the manufacture of dyes.*

[13] *Electrolytic Process (ELECT-tro-LIT-ick). A process that causes the decomposition of a chemical compound by the use of electricity.*

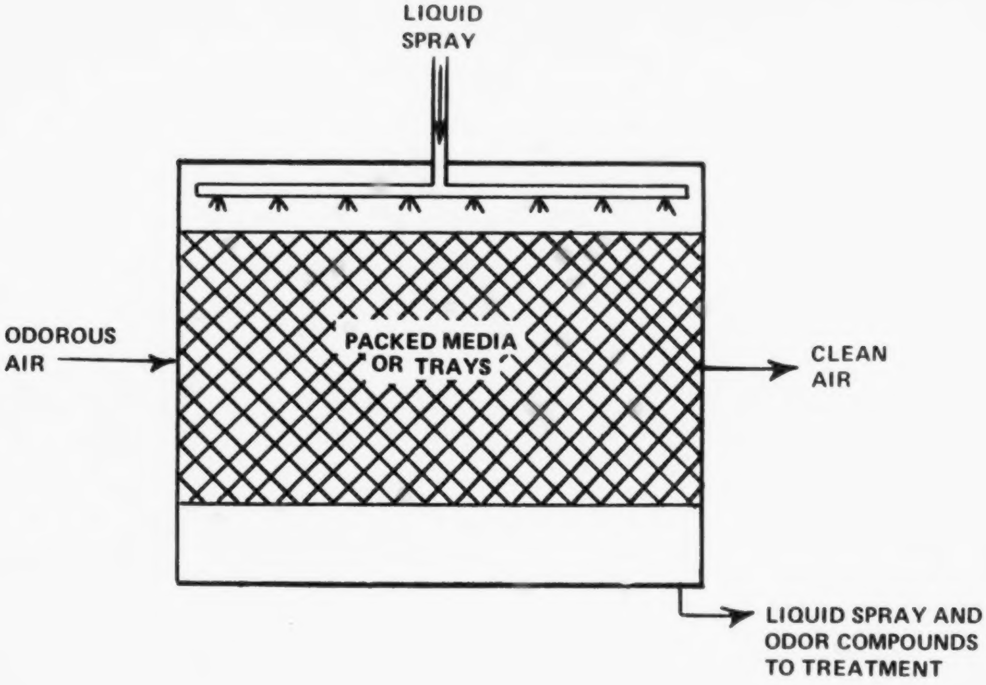
LIQUID SPRAY
ODOROUS AIR
PACKED MEDIA OR TRAYS
CLEAN AIR
LIQUID SPRAY AND ODOR COMPOUNDS TO TREATMENT

Fig. 1.5 Packed media tower or tray tower for odor removal by absorption.

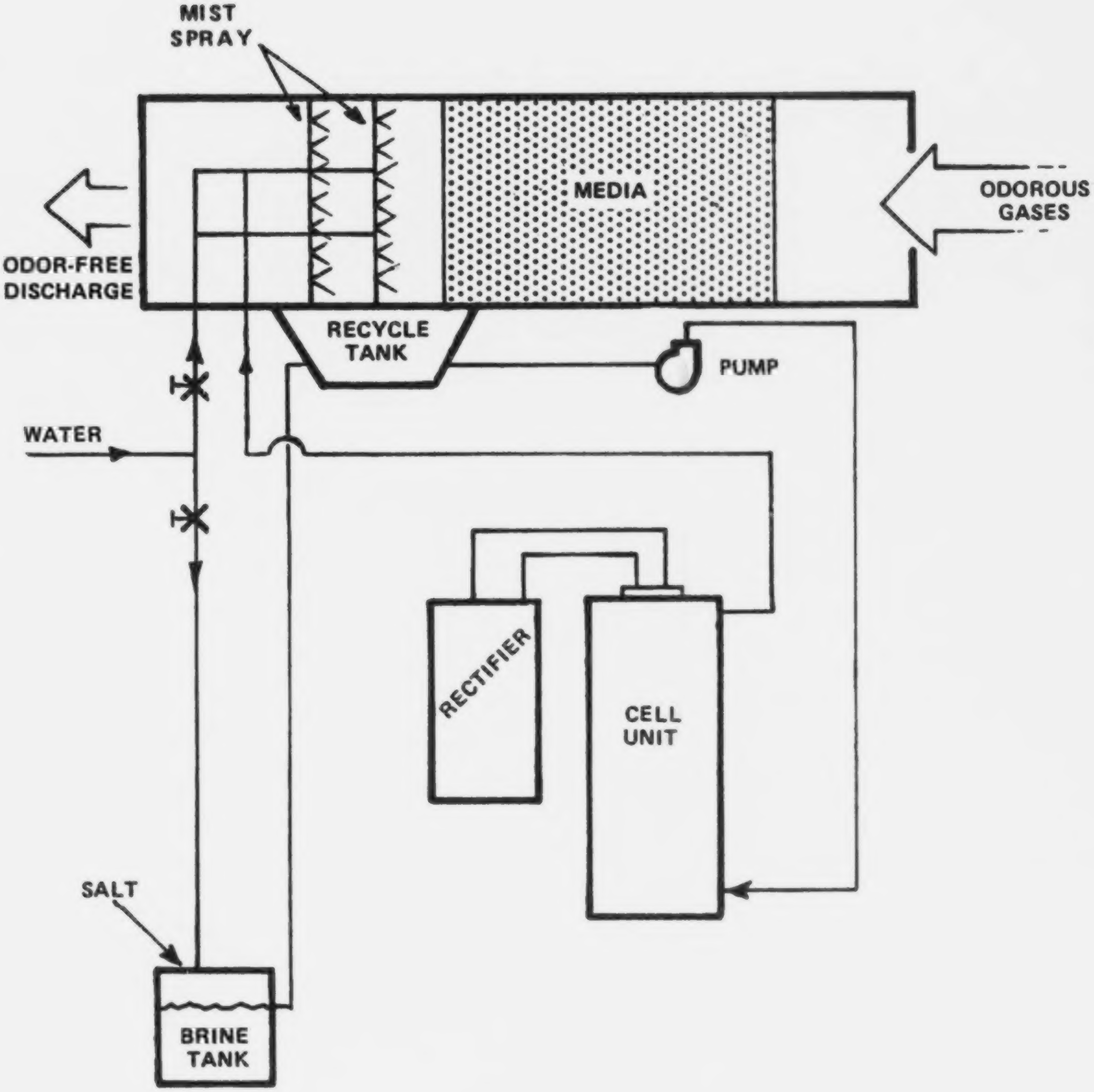
MIST SPRAY
MEDIA
ODOROUS GASES
ODOR-FREE DISCHARGE
RECYCLE TANK
PUMP
WATER
RECTIFIER
CELL UNIT
SALT
BRINE TANK

Fig. 1.6 Brine solution absorption system
(Permission of PEPCON)

Chemical reactions occur at both the anode the cathode. Reactions at the cathode result primarily in the decomposition of water into hydrogen and the hydroxyl ion, whereas the following oxidative reactions occur simultaneously at the anode:

1. Oxidation of chloride to hypochlorite.
2. Formation of other highly oxidative species; namely ozone, singlet oxygen, and peroxides.
3. Electrolysis of water to produce normal gaseous oxygen.

All of these reactions, at both the anode and cathode surfaces, are completely dependent upon the amounts of soluble salts in the circulation stream, and of course, on the output of the rectifier.

1.460 Major Components

For convenience, the major components of this type of odor control unit are summarized under the following headings:

Brine Distribution System. Consists of a separate tank and metering equipment for converting sodium chloride crystals (common salt) into a brine solution. A measurable quantity of the prepared brine is overflowed into the scrubber basin to form the desired concentration of *ELECTROLYTE*.[14]

Cell Recycle System. Comprised of an electrically driven non-corrosive, magnetic pump and associated piping for transferring the solution from the scrubber basin through the cells and then to the scrubbing tower where the solution returns to the basin by gravity.

Electrolytic Unit. Consists of anode-cathode assemblies that are activated through the application of DC power. For simplicity and readability the word CELL will be interchanged with the phrase ANODE-CATHODE ASSEMBLY throughout the remainder of this section.

Fresh Water System. Composed of an incoming line for supplying fresh water to the brine tank and the scrubbing tower.

Rectifier. Comprised of the electrical unit used in converting AC power to DC power.

Scrubbing System. Comprised of non-corrosive recycle pump, vertical tower, a set of spray nozzles, a packing bed and a collection basin.

1.461 Starting Procedure

The scrubber system is designed so that sodium chloride (salt) is converted to hypochlorite in the electrolytic cells (Fig. 1.7) at the rate required to produce the oxidant for destruction or conversion of odorous compounds in the absorption scrubber. The hypochlorite is regenerated after the oxidation of H_2S and other odorous materials. Salt makeup, therefore, is only that required to replace physical losses of chlorine compounds (mainly salt) from the system.

If available, use either a high quality rock salt, one that does not contain an appreciable amount of impurities, or the type of salt recommended for water softeners. Do not use finely granulated table salt as it has a tendency to compact and dissolve slowly.

1. Place about 200 pounds (91 kg) of salt in the brine tank and replenish periodically in order to keep at least 12 inches (30.5 cm) of salt in the tank.
2. Fill the remaining portion of the brine tank with an external source of water.
3. Use an external source to fill the scrubber basin with sufficient water to completely cover both pump intake nozzles. To this quantity of water add about 20 pounds (9 kg) of the same type of salt as was used in filling the brine tank. As a result, an initial source of electrolyte is made available.
4. For achieving an optimum conversion of brine into hypochlorite with the use of the cells after stability has been achieved, the solution in the scrubber basin should contain 30 grams per liter of sodium chloride. Laboratory analyses are required for accurately determining the grams per liter of sodium chloride in solution.
5. Whenever the quantities and types of oxidizable impurities contained within the air stream are not known, refer to Table 20.3 for operating guidelines to determine the optimum level of operation for a 12,000 CFM (5.66 cu m/sec) scrubber.
6. In reference to Table 1.3, the initial operation of the unit should begin at an estimated level of 5 ppm of hydrogen sulfide within the air stream. This suggests setting the brine tank flowmeter at 50 milliliters per minute.
7. Open the valve in the cell pump intake line. Place the cell pump discharge valve in the ¾ open position.

TABLE 1.3 OPERATING GUIDELINES FOR A CHEMICAL SCRUBBER

H_2S, ppm	H_2S, lbs per day[a]	NaCl, lbs per day[a]	Fresh Water to Brine Tank		Fresh water through tower spray nozzles in gallons per day[b]	Total overflow from scrubber basin in gallons per day[b]
			Gals. per day[b]	Milliliters per minute		
1	1.28	7.7	3.7	9.7	9.1	12.8
2	3.56	15.4	7.4	19.4	18.2	25.6
5	6.40	38.5	18.5	48.7	45.5	64
10	12.8	77	37	97.2	91	128
20	25.6	154	74	197.3	182	256

[a] lbs/day × 0.454 = kg/day
[b] gals/day × 3.785 = L/day

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[14] *Electrolyte (ELECT-tro-LIGHT). A substance which dissociates (separates) into two or more ions when it is dissolved in water.*

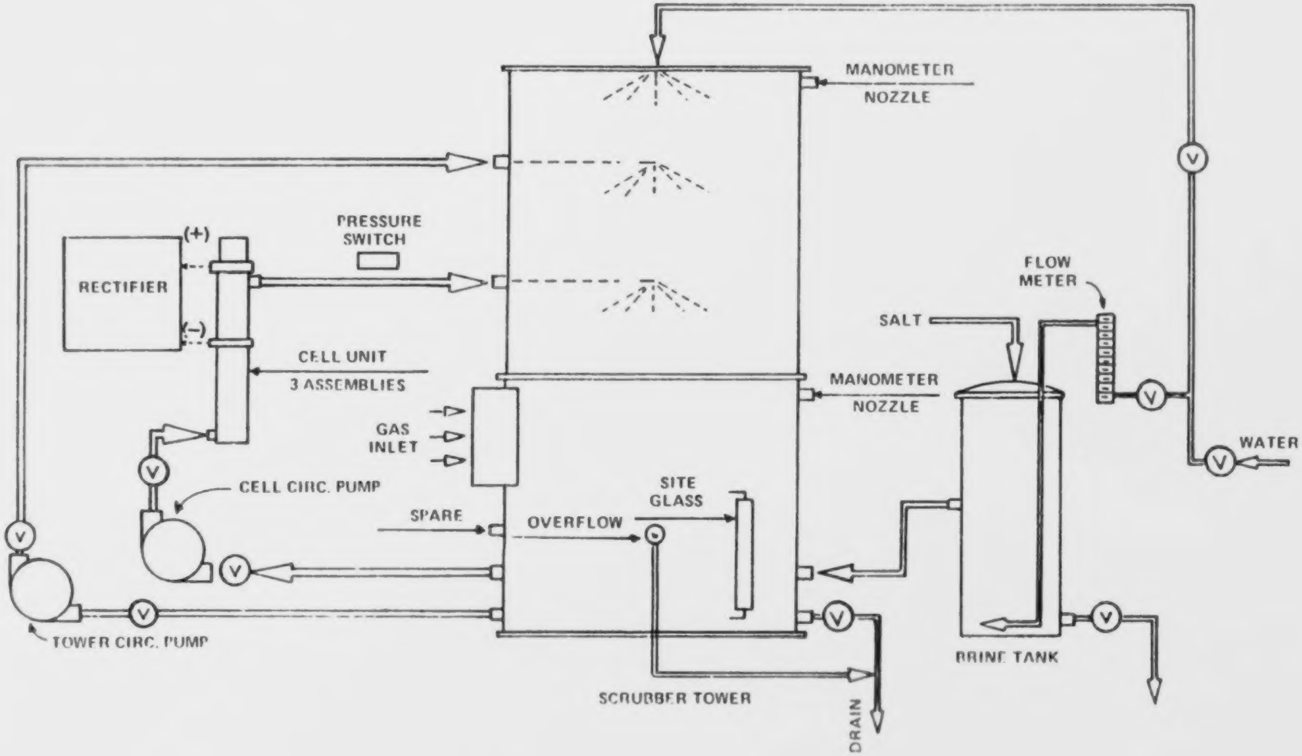
MANOMETER
NOZZLE
PRESSURE SWITCH
(+)
RECTIFIER
(−)
CELL UNIT
3 ASSEMBLIES
FLOW METER
SALT
MANOMETER
NOZZLE
GAS INLET
WATER
CELL CIRC. PUMP
SITE GLASS
SPARE
OVERFLOW
TOWER CIRC. PUMP
BRINE TANK
SCRUBBER TOWER
DRAIN
V

Fig. 1.3 Chemical scrubber system

(Permission of PEPCON)

8. Push the pump start button on the face of the rectifier. The cell pump will begin circulating the solution in the scrubber basin through the cells. Operate the pump for more than a minute before pushing the rectifier control switch to "ON." Flow through the cells can be regulated by adjusting the pump discharge valve. Open the discharge valve about ¾ of its full capacity to insure the magnetic pump does not become overloaded.

   CAUTION: Since the pump works on a magnetic principle and there is little head pressure between the basin and the pump, it may be necessary to momentarily close the discharge valve when starting. Thus the pump creates internal pressure and orients itself magnetically, resulting in almost immediate circulation as the valve is slowly reopened to the ¾ position.

9. Check and determine that the rectifier current control switch is at zero. As previously mentioned, allow the pump to operate more than a minute before pushing the rectifier control switch to "ON." *SOLUTION MUST BE FLOWING THROUGH THE CELLS BEFORE POWER IS APPLIED.* Flow of solution is easily determined by checking the vinyl discharge hoses on the cells. Start the rectifier and then turn the current control switch slowly until the desired operating level is achieved. At the assumed 5 ppm of H_2S within the air stream, set the rectifier at about 500 amps. Adjustments, if necessary, can then be made up or down in 50 amp increments.

   CAUTION: Follow manufacturer's instructions regarding rectifier operation. Do not exceed either the amperage or voltage limits.

10. Open both the intake and discharge valves on the scrubber recycle pump.
11. Start the scrubber recycle pump.
12. After operation has started, should an undesirable odor be detectable near the treatment site, the operator should first increase the output of the rectifier by about 50 amps.

    After about two hours, check and determine whether or not the increase in power was sufficient to eliminate the undesirable odor. If not, increase the output by another 50 amps and continue this procedure until the undesirable odor is eliminated. Similarly, if a hypochlorite odor (smell of household bleach) is detectable near the treatment site and the gas stream is otherwise odor free, *DECREASE* the rectifier setting in 50 amp increments until the hypochlorite odor disappears.

    CAUTION: Do not exceed manufacturer's maximum levels of amperage or voltage under any circumstance.

13. Under the assumed operating level of 5 ppm of H_2S in the gas stream, add approximately 46 gallons (174 liters) of fresh water through the spray nozzles at the top of the tower each day. In order to achieve this desired daily level of overflow from the scrubber basin without hindering the operator's schedule, the fresh water spray valve on the spray line to the upper tower section should be completely opened once each 8-hour shift. During each opening the operator will want to overflow about 16 gallons (61 liters) of water from the scrubber basin.

    This quantity of water is easily determined by collecting the overflow in a container of known quantity. For example, if 2 gallons (7.6 liters) are collected per minute, then it can be assumed 16 gallons (61 liters) will overflow the scrubber basin in 8 minutes.

14. Generally two days of continuous operation are necessary to remove any fluctuation that may occur. In other words, this period of time can be looked upon as the break-in period.

1.462 Shut-Down Procedures

1. Turn the current control knob on the rectifier to zero.
2. Push the "Pump Stop" button on the rectifier panel. Both the pump and the rectifier are simultaneously turned off when this button is pushed.
3. Turn the main rectifier switch to the "OFF" position.
4. Stop the scrubber recycle pump.
5. Shut the flowmeter valve off, if the unit is to be off for more than two hours.

1.463 Operational Checks and Maintenance

This unit requires minimum operator attention; however, several routine checks should be accomplished each day, especially during the initial operating period. The following items can be performed while the system is operating:

1. Keep the vertical hole in the exposed end of each anode filled with silicone oil during the first six weeks of operation. More than likely, the addition of oil will be required once each week during the six-week interval. Use the oil supplied by the manufacturer for servicing the anodes.
2. Once each week for the first six weeks, check for loose nuts on the bus bar and bus bar pieces, and for loose banks around the tops of the cells. Tighten any connections that are loose.
3. Once each day check for the presence of gas bubbles in the vinyl (plastic) discharge tube at the top of each cell. Gas bubbles in the discharge stream reveal the cell is functioning properly and conversely a lack of bubbles suggests the cell is inoperative.
4. Once each day the operator should feel the outside surface of the copper cathode to determine if the assembly is operating at a comparative temperature to the other assemblies and the last daily inspection.
5. If a cell should feel warm, in fact, hot enough to cause an immediate withdrawal of your hand, the condition more than likely reveals a plugged or shorted assembly.
6. A noticeable increase (2 or more Volts) in the output of the rectifier may signify an increase of electrical resistance within the cells. Resistance of this type can result from the formation of a scale-like deposit on the inner walls of the cathode.

   Should an increase in DC voltage ever occur and be noticeable for a period of a day, then the operator can assume a deposit has formed on the cathodes. Cathode scale can be easily removed by flushing the system with dilute nitric acid.

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1.47 Adsorption

"Adsorption" is the process in which the odorous components are removed from a gas through adherence to a solid surface (Fig. 1.8). The attractive force holding the gaseous molecule at the surface may be either physical (physical adsorption) or chemical (chemisorption). Any adsorption process should include a solid with an extremely large capability to adsorb gases. Activated carbon is such a solid.

Activated carbon is a highly porous material. Adsorption takes place upon the walls of the pores within activated carbon. Due to the nonpolar nature of its surface, activated carbon has the ability to adsorb organic and some inorganic materials in preference to water vapor. The materials and amounts adsorbed are dependent upon the physical and chemical makeup of the compound. Adsorption is affected by the molecular weight and boiling point of a compound. Higher molecular weight compounds are usually more strongly adsorbed than lower ones. Activated carbon will adsorb most organics that have molecular weights over 45 and boiling points over 41°F (5°C). Also, activated carbon can be manufactured from several different materials which have considerable variation in their adsorption characteristics.

Activated carbon is an effective means for controlling odors from all areas of the system, such as primary sedimentation and trickling filtration. Odorous air is collected and directed through activated carbon beds where the odor-causing organic gases and some inorganic gases (hydrogen sulfide) are removed from the air and adsorbed on the carbon.

1.470 Process Description

The process consists of a foul-air collection system, ducting, blowers, and activated carbon beds. Foul-air containing odors from various sources in the treatment plant are collected and removed from the air as the odorous air passes through the activated carbon beds. The activated carbon beds consist of several feet of granular activated carbon (Fig. 20.8).

1.471 Start-Up

Inform operating personnel of intent to start blowers.

1. Make sure that the air blower motor electrical switches are off and tagged out.
2. Check to be sure that the blower rotates freely.
3. Make sure all covers are properly in place and are secure.
4. Unlock electrical switches at the main power control center for the blower motor. Turn on electrical power for the blower.
5. Observe blower to make sure it is operating properly.
6. Check carbon bed for air flow.
7. After initial start up, measure air flow above carbon beds with a probe and record the velocity.

1.472 Shut Down

1. Turn electrical power off at blower. If for short duration, this is good enough but it should be tagged. For long duration, turn power off at main power switch and tag and lock out.
2. Inform all operating personnel of status of activated carbon units.
3. If shut down is of a long duration, carbon units should be washed with clean water.

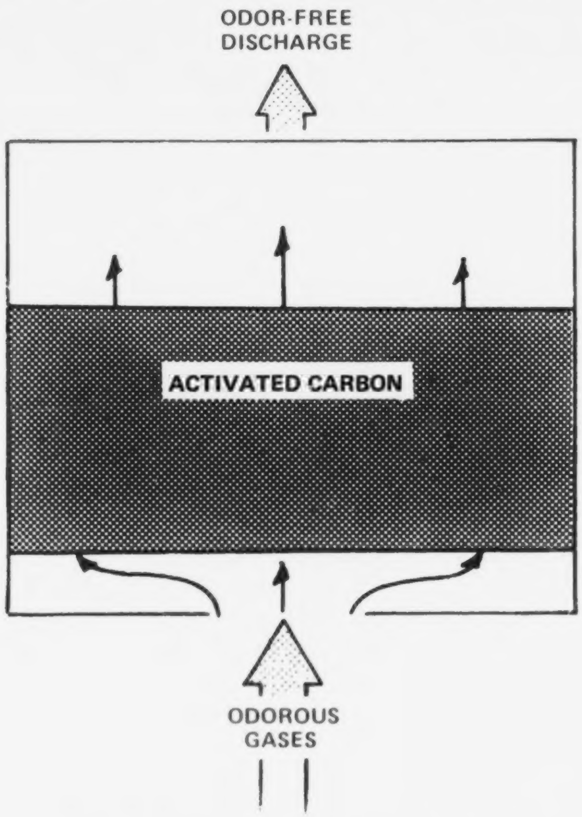

Fig. 1.8 Activated carbon adsorption process

1.473 Operational Checks

DAILY

1. Inspect operation of air blower and motor.
2. Check air flow through the carbon bed.

WEEKLY

1. Measure air flow on the discharge side of the carbon bed with a velocity meter (like the ones used to measure air flow in air conditioning ducts). Compare against initial readings.

   If the air flow is low, the activated carbon is becoming plugged. To unplug the carbon, shut down the blower and spray water over the top of the bed for one hour. Put the unit back in service and recheck the air flow above the carbon bed.

QUARTERLY

1. Measure H_2S levels in the air at various depths in the activated carbon.

   Draw off samples and use an H_2S gas detector. If H_2S levels are found almost all the way through the activated carbon bed, this is an indication that the bed may fail soon. Usually activated carbon beds will regenerate themselves during periods when the odor levels are low.

   If an activated carbon bed fails, consult your supplier for assistance regarding the regeneration or replacement of the activated carbon.

NOTE

1. After activated carbon has been in service for a long period of time and then taken out of service, the carbon may develop a grey appearance. This grey appearance is usually caused by salts which form crystals when the activated carbon drys out. These crystals will cause a grey color, but the activated carbon will still be black.

1.48 Ozonization

Ozonization is an oxidation process (Fig. 1.9). Ozone is a powerful oxidant and can effectively oxidize odor-causing compounds to less objectionable forms. Air is collected from the sources and directed into a mixing chamber where this odorous air is mixed with ozone. The odorous air is oxidized, and the odors are eliminated. Ozone, being relatively unstable, must be manufactured on site.

Successful treatment of odors with ozone depends on the type of odor, intensity or strength of odor, flow rate of odorous air to be treated, and the size of the ozone contact chamber. The longer the contact time, the more effective the treatment. Therefore, control of the ozonization process is achieved by regulating the speed or number of suction fans. Fifteen seconds is considered the minimum mixing and contact time for effective treatment of odors.

1.49 Good Housekeeping

The best solution to odor problems is to prevent odors from ever developing. This can be achieved by good housekeeping. Regularly clean all baffles, weirs, troughs, diversion boxes, channels and all exposed clarifier mechanisms where scum and solids could accumulate and decompose. Cleaning is accomplished by the use of deck brushes with long handles and hosing with a high velocity jet of water. These efforts will help you keep odor problems from becoming a serious public issue.

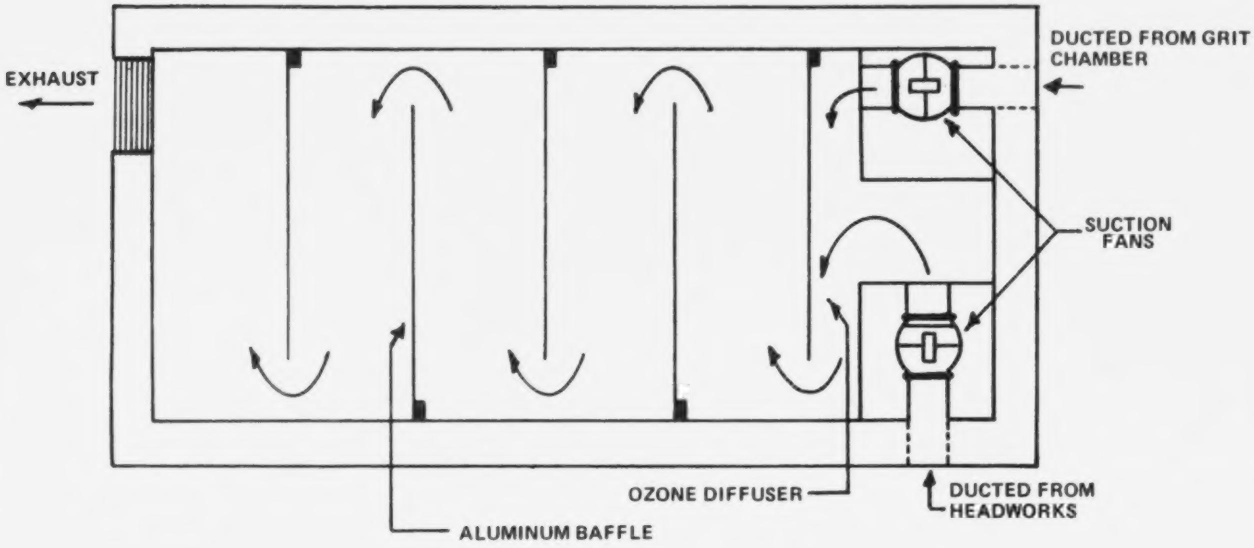

Fig. 1.9 Ozone contact chamber

1.5 TROUBLESHOOTING ODOR PROBLEMS

PLANT AREA	ODOR PROBLEMS	POSSIBLE SOLUTIONS[a]
Influent	H_2S odor	Chemical addition.
	Organic odor	Air stream treatment.[b]
Headworks	H_2S odor	Chemical addition.
	Organic odor	Air stream treatment.[b] Correct faulty plant operation.
Primary sedimentation	H_2S odor	Chemical addition at headworks. Air stream treatment. Remove sludge faster.[b] Chemical addition. Cover tanks, vent odors and treat.
Biological system Activated sludge	Organic odor	Eliminate short-circuiting in aeration chamber.[b] Prevent sludge deposits from developing.
Biological filter	H_2S odor	Air stream treatment. Chemical addition (H_2O_2 in the liquid prior to the filter). Provide even air distribution to the filter to avoid anaerobic areas.[b] Clean filter vents and underdrain system. Correct any design deficiencies.
	Decayed organic odor (ammonia, fishy, rotten cabbage)	Correct any design problems. Chemical addition (H_2O_2, Cl_2, or NO_3^-). Air stream treatment.

[a] Each solution listed may be applied to all odor problems in the plant area where the problem is occurring.
[b] Investigate industrial waste sources as a possible cause of the problem if this item appears to be the correct solution.

1.5 TROUBLESHOOTING ODOR PROBLEMS, (Continued)

PLANT AREA	ODOR PROBLEMS	POSSIBLE SOLUTIONS[a]
Biological system (continued)		
Secondary sedimentation	Organic odor	Correct design problem.
	Inorganic odor	Increase removal rate of sludge. Reduce turbulence that is causing stripping of odor. Increase air in aeration systems. Improve operations.
Anaerobic digestion	Decaying organic odor	Light waste gas burner if not lit.
	Inorganic odor	Correct leaking water seal on floating-cover-type digester. Fixed cover digesters: a. Add water to water seal, and b. Seal cracks in roof. Floating cover digesters: a. Correct leaking water seal, and b. Lower cover until sufficient seal around outside is obtained. Gas equipment: Find and correct leaks around valves, flame assembly, sample wells and access hatch. Look for sources and correct around pop-off valves, vents, drain lines and piping. Check digester opeation.
Sludge handling		
Drying beds	Decaying organic odor	Chemical addition (Countermasking, Masking). Check opeations of digester. Review operations such as withdrawal rate from digester.

[a] Each solution listed may be applicable to all odor problems in the plant area where the problem is occurring.

1.5 TROUBLESHOOTING ODOR PROBLEMS, (Continued)

PLANT AREA	ODOR PROBLEMS	POSSIBLE SOLUTIONS[a]
Biological system (continued)		
Vacuum filters or Filter presses	Organic odor	Check operations. Check operations at digester area. Remove solids from area. Improve housekeeping. Air stream treatment.
Centrifuges	Organic odor	Check operations. Check operations at digesters. Improve housekeeping. Treatment of odors in air removed from centrifuge area.
Sludge retention basins	Organic odor	Review operations.
	Inorganic odor	Develop an aerobic layer on the surface.
Ponds or lagoons	Ammonia odor	Check operations. Review operational data. Chemical addition.
Disinfection	Chlorine smell	Check mixing. Lower dosage rate. Check diffuser. Look for chlorine leaks.
	Ammonia odor	Remove sludge deposits in chamber. Source control. Improve housekeeping.

[a] Each solution listed may be applicable to all odor problems in the plant area where the problem is occurring.

1.6 REVIEW OF PLANS AND SPECIFICATIONS

Odor control facilities require a careful review of the plans and specifications similar to the review given other treatment processes.

1. When clarifiers and other large tanks and areas are enclosed to control odors, be sure provisions are made to lift covers over tanks for inspection and maintenance purposes. Movable cranes or hoists are helpful.
2. Hydrogen sulfide gas combines with moisture to form sulfuric acid which is very corrosive. All concrete must be protected from corrosion. All pipes, vents, screens, grates, support systems, and other materials exposed to odorous air must be made of corrosion resistant materials.
3. Be sure provisions are made for ventilation of enclosed spaces with fresh air before anyone enters enclosed spaces for any reason. Equipment and instruments must be available to detect hydrogen sulfide, explosive conditions and an oxygen deficiency in enclosed atmospheres before entry.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 29.

1.4K How can odors in air be treated?

1.4L What is a solid that is used in an adsorption process to remove odors from air?

1.4M When operating a chemical scrubber unit using a brine solution, how would you determine if the rectifier output is set properly or is set too high or too low?

1.7 ADDITIONAL READING

1. *MOP 11,* Chapter 27,* "Odor Control."
2. "Ozonization of Septic Odors at a Pretreatment Facility." Water Pollution Control Federation, Deeds & Data, July, 1977, p. D-1.
3. *ODOR CONTROL FOR WASTEWATER FACILITIES* (MOP 22). Obtain from Publications Order Department, Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994. Order No. M0028. Price to members, $6.00; nonmembers, $8.00.

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* *Depends on edition.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 1. ODOR CONTROL

Work these discussion and review questions before continuing with the Objective Test. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. How would you determine the source and cause of odors and a solution to the problem?
2. How should an odor complaint be handled?
3. What can happen if an odor complaint is handled improperly?
4. How can odorous gases be treated?
5. What would you do if persons living near your treatment plant complained of a chlorine smell?

PLEASE WORK THE OBJECTIVE TEST NEXT.

SUGGESTED ANSWERS

Chapter 1. ODOR CONTROL

Answers to questions on page 8.

1.0A Wastewater is tending to become more septic, and thus causing odor and corrosion problems, because collection systems are being extended farther and farther away from treatment plants.

1.1A The principal source of odor generation is from the production of inorganic and organic gases by microorganisms. Odors also may be produced when odor-containing or odor-generating materials are discharged into the collection system by industries and businesses.

1.1B The main inorganic gases of concern to operators are hydrogen sulfide (H_2S) and ammonia (NH_3).

1.1C The order in which microorganisms utilize oxygen in nature is: molecular oxygen (free dissolved oxygen), nitrate, sulfate, oxidized organics, and carbon dioxide.

1.1D The major source of inorganic odor-producing sulfate compounds found in collection systems and treatment plants is sulfate compounds from the public water supply and from industrial sources.

1.1E Hydrogen sulfide causes problems at lower or acidic pH ranges. At a pH below 5, all sulfide is present in the gaseous H_2S form and most of it can be released from wastewater to cause odor, corrosion, explosive conditions and respiratory problems.

Answers to questions on page 12.

1.2A Odors can be measured by the use of an olfactometer.

1.2B Usually smells can be classified into the following groups:

1. Ammonia
2. Decayed cabbage
3. Fecal
4. Fishy
5. Garlic
6. Medicinal
7. Rotten egg
8. Skunk

1.3A Never approach a person who has an odor complaint with a negative attitude.

1.3B You might not be able to detect an odor disturbing a person complaining because:

1. Your nose may not be as sensitive as the nose of the person complaining, and
2. Your nose may be accustomed to the smell, and may no longer be able to detect the offensive odor.

Answers to questions on page 14.

1.4A Systematic steps to follow to solve an odor problem include:

1. Review plant operations,
2. Review plant performance,
3. Evaluate plant performance,
4. Review engineering or design features of the plant,
5. Make an on-site inspection and investigation of the problem areas,
6. Attempt to identify the source or cause of the problem,
7. List and review all solutions to the problem, and
8. Put into practice the best possible solution.

1.4B The most important role that chlorine plays in controlling odors is to inhibit the growth of odor-causing microorganisms.

1.4C Three possible ways hydrogen peroxide reacts to control odors are (1) oxidant action, (2) oxygen producing, and (3) bactericidal to the sulfate-reducing bacteria.

Answers to questions on page 14.

1.4D Oxygen is used to control odors by aerating wastewater and attempting to keep it aerobic. Also, aeration can strip odors out of wastewater.

1.4E A limitation of using metallic ions to precipitate sulfide is the toxic effect on biological processes such as digestion.

1.4F Odors can be controlled by increasing the pH. At pH levels above 9.0, biological slimes and sludge growths are inhibited. Also, any sulfide present will be in the form of HS^- ion or S^{-2} ion, rather than as H_2S gas which is formed and released at low pH values.

Answers to questions on page 17.

1.4G Off-gases and foul air are treated in a biological odor reduction tower by passing up through the filter media where the odors are oxidized to an acceptable odor level.

1.4H The filter feed is spread over the media by the use of spray nozzles.

1.4I The pH of the spray water should not be allowed to drop below 6.0 because the water will cause corrosion damage.

1.4J The pH of the spray water can be increased by the addition of caustic soda.

Answers to questions on page 27.

1.4K Odors in air can be treated by masking and counteraction, combustion, absorption, adsorption and ozonization. Perhaps the best treatment is to prevent odors from forming.

1.4L Activated carbon is a solid that is used to remove odors from air by the adsorption process.

1.4M If the rectifier output is set too high, a hypochlorite odor (smell of household bleach) is detectable. If the output is set too low, an undesirable odor is detectable. No odors are detectable if the rectifier is set properly.

OBJECTIVE TEST

Chapter 1. ODOR CONTROL

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1, Volume I, *OPERATION OF WASTEWATER TREATMENT PLANTS*. There may be more than one correct answer to each question.

1. The reaction of chlorine to control odors with certain chemicals can produce a more odorous gas.
    1. True
    2. False

2. Ozonization is an oxidation process using ozone.
    1. True
    2. False

3. Activated carbon will not remove hydrogen sulfide from odorous air.
    1. True
    2. False

4. Good housekeeping is not an effective means of controlling odors.
    1. True
    2. False

5. Operators do not have to worry about odor complaints.
    1. True
    2. False

6. Adsorption is the taking in or soaking up of one substance into the body of another substance.
    1. True
    2. False

7. An olfactometer is a device used to measure odors.
    1. True
    2. False

8. Gas bubbles in the discharge tube at the top of each cell in a chemical scrubber reveal that the cell is functioning properly and conversely a lack of bubbles suggests the cell is inoperative.
    1. True
    2. False

9. If a cell in a chemical scrubber feels hot enough to cause an immediate withdrawal of your hand, the condition reveals that everything is functioning properly.
    1. True
    2. False

10. In a biological odor reduction tower, odors will not be removed from the gas stream until a biomass is established on the filter media.
    1. True
    2. False

11. What is the order in which microorganisms break down compounds containing oxygen in nature?
    1. Carbon dioxide, nitrate and sulfate
    2. Carbon dioxide, sulfate and nitrate
    3. Nitrate, carbon dioxide and sulfate
    4. Nitrate, sulfate and carbon dioxide
    5. Sulfate, nitrate and carbon dioxide

12. Hydrogen sulfide causes the most serious problems at what pH range?
    1. Less than 5
    2. 5 to 7
    3. 7, neutral
    4. 7 to 9
    5. Greater than 9

13. Always approach a person with an odor complaint with a(n) ________________ attitude (select best answer).
    1. Impatient
    2. Negative
    3. Official
    4. Positive
    5. Superior

14. Odors in *AIR* can be treated by
    1. Absorption.
    2. Adsorption.
    3. Metallic ions.
    4. Ozonization.
    5. pH adjustment.

15. Low air flow readings indicate that an activated carbon bed is becoming plugged. The proper procedure to unplug the bed is to
    1. Dose the bed with acid.
    2. Rake the surface of the bed.
    3. Remove the activated carbon and replace it.
    4. Spray water over the top of the bed.
    5. Wash the bed with a high pressure spray.

16. Which type(s) of salt may be used for salt makeup in a chemical scrubber system?
    1. Brine salt
    2. High quality rock salt
    3. Pharmaceutical salt
    4. Table salt
    5. Water softener salt

17. Smells or odors usually can be classified into which of the following groups?
    1. Ammonia
    2. Fecal
    3. Pig
    4. Skunk
    5. Swamp

18. Steps followed (not in order) in procedures used when attempting to solve odor problems include
    1. Evaluation of plant performance.
    2. Examination of engineering or design features of plant.
    3. Identification of source or cause of problem.
    4. On-site inspection and investigation of the problem areas.
    5. Review of plant housekeeping.

END OF OBJECTIVE TEST

CHAPTER 2

ACTIVATED SLUDGE

Pure Oxygen Plants and Operatonal Control Options

by

Ross Gudgel

and

Larry Peterson

OPERATION OF WASTEWATER TREATMENT PLANTS

Volume I, Chapter 8
Package Plants and Oxidation Ditches

Volume II, Chapter 11
Operation of Conventional Activated Sludge Plants

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INDUSTRIAL WASTE TREATMENT

OBJECTIVES

Chapter 2. ACTIVATED SLUDGE

Pure Oxygen Plants and Operational Control Options

Following completion of Chapter 2, you should be able to:

1. Safely operate and maintain a pure oxygen activated sludge plant,
2. Review the plans and specifications for a pure oxygen system,
3. Describe the various methods of determining return sludge and waste sludge rates and select the best method for your plant,
4. Operate an activated sludge process that must treat both municipal and industrial wastes,
5. Operate an activated sludge process that must treat strictly an industrial waste, and
6. Operate an activated sludge process to produce a nitrified effluent.

GLOSSARY

Chapter 2. ACTIVATED SLUDGE

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACTIVATED SLUDGE (ACK-ta-VATE-ed sluj) ACTIVATED SLUDGE

Sludge particles produced in raw or settled wastewater (primary effluent) by the growth of organisms (including zoogleal bacteria) in aeration tanks in the presence of dissolved oxygen. The term "activated" comes from the fact that the particles are teeming with bacteria, fungi, and protozoa. Activated sludge is different from primary sludge in that the sludge particles contain many living organisms which can feed on the incoming wastewater.

ACTIVATED SLUDGE PROCESS (ACK-ta-VATE-ed sluj) ACTIVATED SLUDGE PROCESS

A biological wastewater treatment process which speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to wastewater and the mixture (mixed liquor) is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank) as needed. The remaining wastewater then undergoes more treatment.

ADSORPTION (add-SORP-shun) ADSORPTION

The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another substance.

AERATION LIQUOR (air-A-shun) AERATION LIQUOR

Mixed liquor. The contents of the aeration tank including living organisms and material carried into the tank by either untreated wastewater or primary effluent.

AERATION TANK (air-A-shun) AERATION TANK

The tank where raw or settled wastewater is mixed with return sludge and aerated. The same as aeration bay, aerator, or reactor.

AEROBES AEROBES

Bacteria that must have molecular (dissolved) oxygen (DO) to survive.

AEROBIC DIGESTION (AIR-O-bick) AEROBIC DIGESTION

The breakdown of wastes by microorganisms in the presence of dissolved oxygen. Waste sludge is placed in a large aerated tank where aerobic microorganisms decompose the organic matter in the sludge. This is an extension of the activated sludge process.

AGGLOMERATION (a-GLOM-er-A-shun) AGGLOMERATION

The growing or coming together of small scattered particles into larger flocs or particles which settle rapidly. Also see FLOC.

AIR LIFT AIR LIFT

A special type of pump. This device consists of a vertical riser pipe submerged in the wastewater or sludge to be pumped. Compressed air is injected into a tail piece at the bottom of the pipe. Fine air bubbles mix with the wastewater or sludge to form a mixture lighter than the surrounding water which causes the mixture to rise in the discharge pipe to the outlet. An air-lift pump works similar to the center stand in a percolator coffee pot.

ALIQUOT (AL-li-kwot) ALIQUOT

Portion of a sample.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surroundings.

ANAEROBES ANAEROBES

Bacteria that do not need molecular (dissolved) oxygen (DO) to survive.

BACTERIAL CULTURE (back-TEAR-e-al) BACTERIAL CULTURE

In the case of activated sludge, the bacterial culture refers to the group of bacteria classed as *AEROBES*, and facultative organisms, which covers a wide range of organisms. Most treatment processes in the United States grow facultative organisms which utilize the carbonaceous (carbon compounds) BOD. Facultative organisms can live when oxygen resources are low. When "nitrification" is required, the nitrifying organisms are *OBLIGATE AEROBES* (require oxygen) and must have at least 0.5 mg/*L* of dissolved oxygen throughout the whole system to function properly.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated, and the tank is emptied. The tank may then be filled and the process repeated.

BENCH SCALE ANALYSIS BENCH SCALE ANALYSIS

A method of studying different ways of treating wastewater and solids on a small scale in a laboratory.

BIOMASS (BUY-o-MASS) BIOMASS

A mass or clump of living organisms feeding on the wastes in wastewater, dead organisms and other debris. This mass may be formed for, or function as, the protection against predators and storage of food supplies. Also see ZOOGLEAL MASS.

BULKING (BULK-ing) BULKING

Clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge becomes too light and will not settle properly.

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of steel and iron surfaces in contact with water, wastewater or soil.

CILIATES (SILLY-ates) CILIATES

A class of protozoans distinguished by short hairs on all or part of their bodies.

COAGULATION (ko-AGG-you-LAY-shun) COAGULATION

The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, and draining or filtering.

COMPOSITE (PROPORTIONAL) SAMPLE (com-POZ-it) COMPOSITE (PROPORTIONAL) SAMPLE

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

CONING (CONE-ing) CONING

Development of a cone-shaped flow of liquid, like a whirlpool, through sludge. This can occur in a sludge hopper during sludge withdrawal when the sludge becomes too thick. Part of the sludge remains in place while liquid rather than sludge flows out of the hopper. Also called "coring."

CONTACT STABILIZATION CONTACT STABILIZATION

Contact stabilization is a modification of the conventional activated sludge process. In contact stabilization, two aeration tanks are used. One tank is for separate re-aeration of the return sludge for at least four hours before it is permitted to flow into the other aeration tank to be mixed with the primary effluent requiring treatment.

CRYOGENIC (cry-o-JEN-nick) CRYOGENIC

Low temperature.

DENITRIFICATION DENITRIFICATION

A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers.

DIFFUSED-AIR AERATION DIFFUSED-AIR AERATION

A diffused air activated sludge plant takes air, compresses it, and then discharges the air below the water surface of the aerator through some type of air diffusion device.

DIFFUSER DIFFUSER

A device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in an aeration tank or reactor.

DISSOLVED OXYGEN DISSOLVED OXYGEN

Molecular oxygen dissolved in water or wastewater, usually abbreviated DO.

ENDOGENOUS (en-DODGE-en-us) ENDOGENOUS

A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.

F/M RATIO F/M RATIO

Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

$$\frac{\text{Food}}{\text{Microorganisms}} = \frac{\text{BOD, lbs/day}}{\text{MLVSS, lbs}}$$

$$= \frac{\text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34\text{ lbs/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/}L \times 8.34\text{ lbs/gal}}$$

$$\text{or} \quad = \frac{\text{BOD, kg/day}}{\text{MLVSS, kg}}$$

FACULTATIVE (FACK-ul-TAY-tive) FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FILAMENTOUS BACTERIA (FILL-a-MEN-tuss) FILAMENTOUS BACTERIA

Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomycetes.

FLIGHTS FLIGHTS

Scraper boards, made from redwood or other rot-resistant woods or plastic, used to collect and move settled sludge or floating scum.

FLOC FLOC

Groups or clumps of bacteria that have come together and formed a cluster. Found in aeration tanks and secondary clarifiers.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles.

FOOD/MICROORGANISM RATIO FOOD/MICROORGANISM RATIO

Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

$$\frac{\text{Food}}{\text{Microorganisms}} = \frac{\text{BOD, lbs/day}}{\text{MLVSS, lbs}}$$

$$= \frac{\text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34\text{ lbs/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/}L \times 8.34\text{ lbs/gal}}$$

$$\text{or} \quad = \frac{\text{BOD, kg/day}}{\text{MLVSS, kg}}$$

Commonly abbreviated F/M Ratio.

HEADER HEADER

A large pipe to which the ends of a series of smaller pipes are connected. Also called a "manifold."

INTERFACE INTERFACE

The common boundary layer between two fluids such as a gas (air) and a liquid (water) or a liquid (water) and another liquid (oil).

MCRT MCRT

Mean **C**ell **R**esidence **T**ime, days. An expression of the average time that a microorganism will spend in the activated sludge process.

$$\text{MCRT, days} = \frac{\text{Solids in Activated Sludge Process, lbs}}{\text{Solids Removed from Process, lbs/day}}$$

MLSS MLSS

Mixed **L**iquor **S**uspended **S**olids, mg/*L*. Suspended solids in the mixed liquor of an aeration tank.

MLVSS MLVSS

Mixed **L**iquor **V**olatile **S**uspended **S**olids, mg/*L*. The organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present.

MANIFOLD MANIFOLD

A large pipe to which the ends of a series of smaller pipes are connected. Also called a "header."

MEAN CELL RESIDENCE TIME (MCRT) MEAN CELL RESIDENCE TIME (MCRT)

An expression of the average time that a microorganism will spend in the activated sludge process.

$$\text{MCRT, days} = \frac{\text{Solids in Activated Sludge Process, lbs}}{\text{Solids Removed from Process, lbs/day}}$$

MECHANICAL AERATION MECHANICAL AERATION

The use of machinery to mix air and water so that oxygen can be absorbed into the water. Some examples are: paddle wheels, mixers, or rotating brushes to agitate the surface of an aeration tank; pumps to create fountains; and pumps to discharge water down a series of steps forming falls or cascades.

MICROORGANISMS (micro-ORGAN-is-ums) MICROORGANISMS

Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

MIXED LIQUOR MIXED LIQUOR

When the activated sludge in an aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank. Mixed liquor also may refer to the contents of mixed aerobic or anaerobic digesters.

MIXED LIQUOR SUSPENDED SOLIDS (MLSS) MIXED LIQUOR SUSPENDED SOLIDS (MLSS)

Suspended solids in the mixed liquor of an aeration tank.

MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS) MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS)

The organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present.

MOVING AVERAGE MOVING AVERAGE

To calculate the moving average for the last 7 days, add up the values for the last 7 days and divide by 7. Each day add the most recent day to the sum of values and subtract the oldest value. By using the 7-day moving average, each day of the week is always represented in the calculations.

NITRIFICATION (NYE-tri-fi-KAY-shun) NITRIFICATION

A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the "nitrification stage" (first-stage BOD is called the "carbonaceous stage").

OXIDATION (ox-i-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

POLYELECTROLYTE (POLY-electro-light) POLYELECTROLYTE

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."

POLYMER (POLY-mer) POLYMER

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."

PROTOZOA (pro-toe-ZOE-ah) PROTOZOA

A group of microscopic animals (usually single-celled) that sometimes cluster into colonies.

PURGE PURGE

To remove a gas or vapor from a vessel, reactor, or confined space.

RAS RAS

Return Activated Sludge, mg/*L*. Settled activated sludge that is collected in the secondary clarifier and returned to the aeration basin to mix with incoming raw or primary settled wastewater.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions in wastewater, sulfate compounds or elemental sulfur is reduced to odor-producing hydrogen sulfide (H_2S) or the sulfide ion (S^{-2}). The opposite of OXIDATION.

RETURN ACTIVATED SLUDGE (RAS) RETURN ACTIVATED SLUDGE (RAS)

Settled activated sludge that is collected in the secondary clarifier and returned to the aeration basin to mix with incoming raw or primary settled wastewater.

RISING SLUDGE RISING SLUDGE

Rising sludge occurs in the secondary clarifiers of activated sludge plants when the sludge settles to the bottom of the clarifier, is compacted, and then starts to rise to the surface, usually as a result of denitrification.

ROTIFERS (ROE-ti-fers) ROTIFERS

Microscopic animals characterized by short hairs on their front end.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded secchi disc reading.

SEIZING SEIZING

Seizing occurs when an engine overheats and a component expands to the point where the engine will not run. Also called "freezing."

SEPTIC (SEP-tick) SEPTIC

This condition is produced by anaerobic bacteria. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

SHOCK LOAD SHOCK LOAD

The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems. Possible problems include odors and solids in the effluent. Organic or hydraulic overloads can cause a shock load.

SLUDGE AGE SLUDGE AGE

A measure of the length of time a particle of suspended solids has been undergoing aeration in the activated sludge process.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids Under Aeration, lbs or kg}}{\text{Suspended Solids Added, lbs/day or kg/day}}$$

SLUDGE DENSITY INDEX (SDI) SLUDGE DENSITY INDEX (SDI)

This test is used in a way similar to the Sludge Volume Index (SVI) to indicate the settleability of a sludge in a secondary clarifier or effluent. SDI = 100/SVI. Also see SLUDGE VOLUME INDEX (SVI).

SLUDGE VOLUME INDEX (SVI) SLUDGE VOLUME INDEX (SVI)

This is a test used to indicate the settling ability of activated sludge (aeration solids) in the secondary clarifier. The test is a measure of the volume of sludge compared to its weight. Allow the sludge sample from the aeration tank to settle for 30 minutes. Then calculate SVI by dividing the volume (ml) of wet settled sludge by the weight (mg) of the sludge after it has been dried. Sludge with an SVI of one hundred or greater will not settle as readily as desirable because it is as light as or lighter than water.

$$\text{SVI} = \frac{\text{Wet Settled Sludge, ml}}{\text{Dried Sludge Solids, mg}} \times 1000$$

STABILIZED WASTE STABILIZED WASTE

A waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

STEP-FEED AERATION STEP-FEED AERATION

Step-feed aeration is a modification of the conventional activated sludge process. In step aeration, primary effluent enters the aeration tank at several points along the length of the tank, rather than all of the primary effluent entering at the beginning or head of the tank and flowing through the entire tank.

STRIPPED GASES STRIPPED GASES

Gases that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed or tumbled over media.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or to the primary clarifier.

TOC TOC

Total **O**rganic **C**arbon. TOC measures the amount of organic carbon in water.

TURBIDITY METER TURBIDITY METER

An instrument for measuring the amount of particles suspended in water. Precise measurements are made by measuring how light is scattered by the suspended particles. The normal measuring range is 0 to 100 and is expressed as Nephelometric Turbidity Units (NTU's).

VOLUTE (vol-LOOT) VOLUTE

The spiral-shaped casing which surrounds a pump, blower, or turbine impeller and collects the liquid or gas discharged by the impeller.

WAS WAS

Waste **A**ctivated **S**ludge, mg/*L*. The excess growth of microorganisms which must be removed from the process to keep the biological system in balance.

WASTE ACTIVATED SLUDGE (WAS) WASTE ACTIVATED SLUDGE (WAS)

The excess growth of microorganisms which must be removed from the process to keep the biological system in balance.

ZOOGLEAL MASS (ZOE-glee-al) ZOOGLEAL MASS

Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes. These masses may be formed for or function as the protection against predators and for storage of food supplies. Also see BIOMASS.

ATOZ (Aye to
.....ATO Z

CHAPTER 2. ACTIVATED SLUDGE

Pure Oxygen Plants and Operational Control Options

(Lesson 1 of 4 Lessons)

NOTE: Review Volume I, Chapter 8, and Volume II, Chapter 11, of *OPERATION OF WASTEWATER TREATMENT PLANTS* for additional information.

2.0 THE ACTIVATED SLUDGE PROCESS

Research and operational experience are gradually revealing how the activated sludge process treats wastes and how to control the process. One objective of this chapter is to provide operators with a better understanding of the factors that can upset an activated sludge process and how to control the process to produce a high quality effluent. Pure oxygen systems dissolve oxygen into wastewater with a high efficiency for use by microorganisms treating the wastes. This allows the use of smaller aeration (reactor) tanks than air activated sludge systems. Operators need greater skill and knowledge to operate pure oxygen systems than conventional systems.

Operation of either pure oxygen or conventional aeration activated sludge processes is very complex. The quality of your plant's effluent depends on the characteristics of the plant's influent flows and wastes, as well as how the actual process is controlled. Two very important factors are:

1. RETURN ACTIVATED SLUDGE (RAS) RATE, and
2. WASTE ACTIVATED SLUDGE (WAS) RATE.

Several methods have been developed to help operators select the proper rates. This chapter reviews some of these methods and their advantages and limitations. You must remember that each of these factors affects the others and the impact on all process variables must be considered before changing one variable.

Some NPDES permits require the removal of ammonia from plant effluents. Biological nitrification (converting ammonium (NH_4^+) to nitrate (NO_3^-) is the most effective way to remove ammonia unless total nitrogen removal is necessary. If total nitrogen removal is required, biological nitrification is the first step of the biological nitrification-denitrification approach to nitrogen removal. The biological nitrification process is an extension of the activated sludge process and is operated on the basis of the same concepts.

Industrial wastes are becoming more common in many municipal wastewaters. Whether you operate an activated sludge plant in a small town or a large city, you must know how to treat the industrial wastes that may be present with your municipal wastewaters. Many industries pretreat their own wastewaters before discharge to municipal collection systems while other industries treat all of their wastewaters rather than discharge into municipal collection systems. Whether you are treating strictly industrial wastewaters or a mixture of industrial and municipal wastewaters, this chapter will provide you with the information you need to know to safely treat these different types of wastewaters using the activated sludge process.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

2.0A Why are pure oxygen systems used instead of conventional aeration methods?

2.0B What treatment process can be used to remove ammonium (NH_4^+) from wastewater, but not total nitrogen?

2.1 PURE OXYGEN

2.10 Description of Pure Oxygen Systems

The pure oxygen system (Fig. 2.1) is a modification of the activated sludge process (Fig. 2.2). The main difference is the method of supplying dissolved oxygen to the activated sludge process. In other activated sludge processes, air is compressed and released under water to produce an air-water *INTERFACE*[1] that transfers oxygen into the water (dissolved oxygen). If compressed air is not used, surface aerators agitate the water surface to drive air into the water (dissolved oxygen) to obtain the oxygen transfer. In the pure oxygen system, the only real differences are that pure oxygen rather than air is released below the surface or driven into the water by means of surface aerators and the aerators are covered.

In the pure oxygen system, oxygen is first separated from the air to produce relatively high-purity oxygen (90 to 98 percent oxygen). Pure oxygen is applied to the wastewater as a source of oxygen for the microorganisms treating the wastes. As with forced-air activated sludge systems, the pure oxygen must be driven into the water. This is accomplished by a diffuser mechanism or by mechanical agitation consisting of *TURBULENT MIXERS*[2] and surface aerators. The agitators also supply the energy to mix the reactor (aeration tank) contents to distribute the waste food (measured as BOD or COD) to the activated sludge microorganisms in the mixed liquor suspended solids (MLSS) and to prevent buildup of MLSS deposits in the reactor.

The pure oxygen reactors are staged (divided into two to five sections by baffles as shown in the three-stage system on Fig. 2.3) and are completely covered to provide a gas-tight enclosure. The wastewater, return sludge, and oxygen are fed into the first stage. The mixed liquor and atmosphere above it flow in the same direction from the first stage to the last.

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[1] ***Interface.** The common boundary layer between two fluids such as a gas (air) and a liquid (water) or a liquid (water) and another liquid (oil).*

[2] ***Turbulent Mixers.** Devices that mix air bubbles and water and cause turbulence to dissolve oxygen in water.*

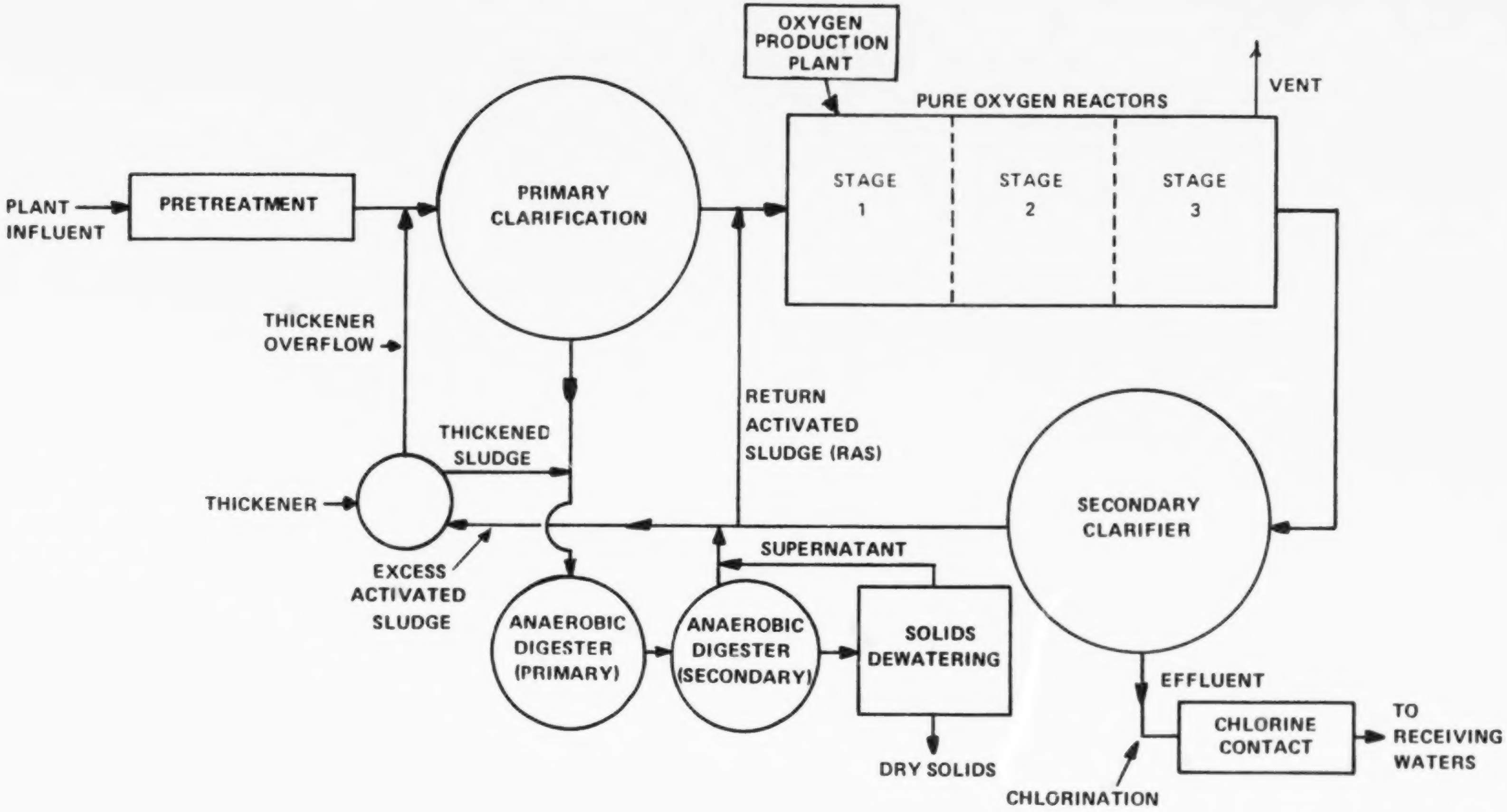
OXYGEN PRODUCTION PLANT
PURE OXYGEN REACTORS
VENT
PLANT INFLUENT
PRETREATMENT
PRIMARY CLARIFICATION
STAGE 1
STAGE 2
STAGE 3
THICKENER OVERFLOW
RETURN ACTIVATED SLUDGE (RAS)
THICKENED SLUDGE
THICKENER
SECONDARY CLARIFIER
SUPERNATANT
EXCESS ACTIVATED SLUDGE
ANAEROBIC DIGESTER (PRIMARY)
ANAEROBIC DIGESTER (SECONDARY)
SOLIDS DEWATERING
EFFLUENT
CHLORINE CONTACT
TO RECEIVING WATERS
DRY SOLIDS
CHLORINATION

Fig. 2.1 Plan layout of a typical pure oxygen activated sludge plant

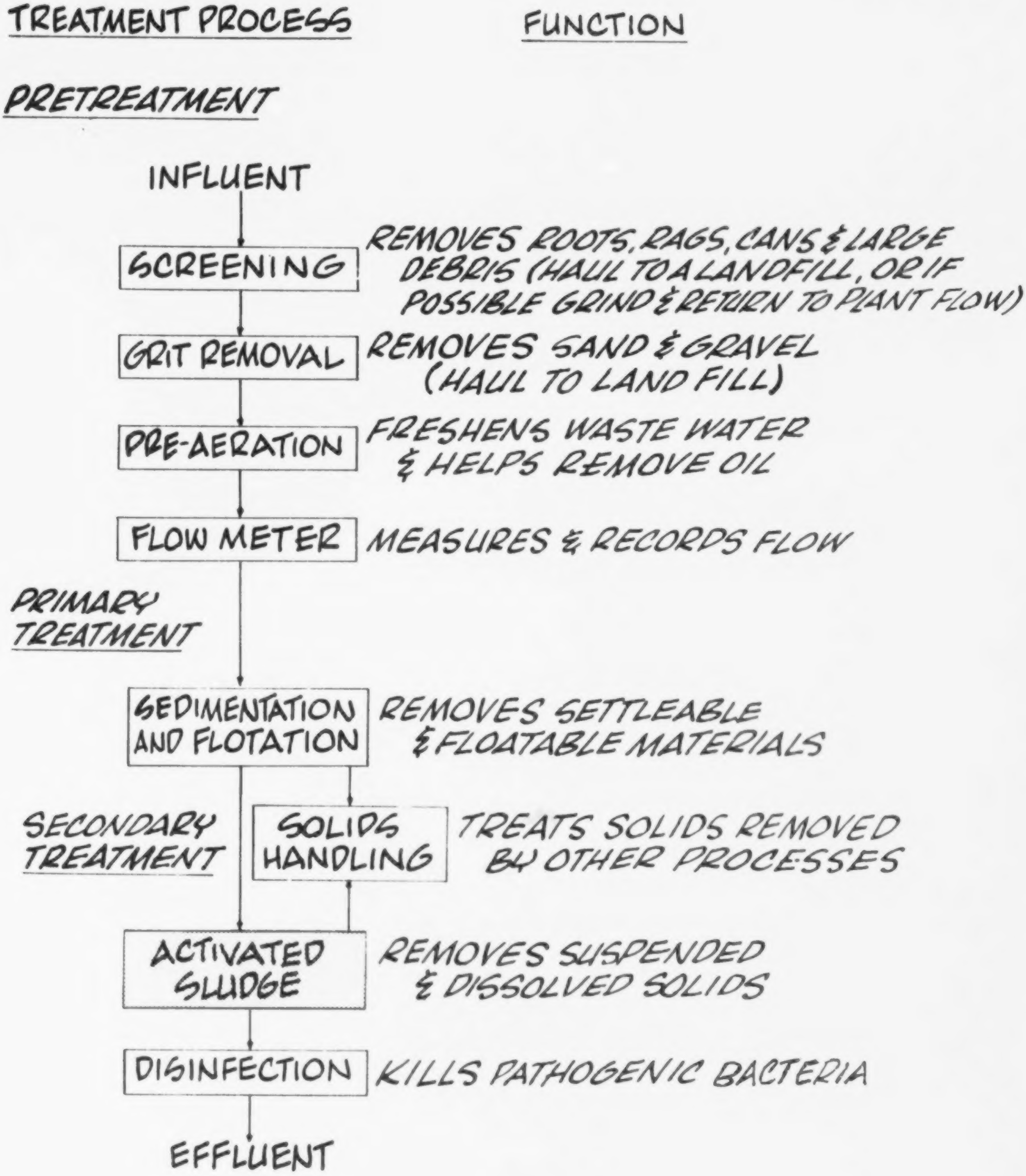
TREATMENT PROCESS
FUNCTION
PRETREATMENT
INFLUENT
SCREENING
REMOVES ROOTS, RAGS, CANS & LARGE DEBRIS (HAUL TO A LANDFILL, OR IF POSSIBLE GRIND & RETURN TO PLANT FLOW)
GRIT REMOVAL
REMOVES SAND & GRAVEL (HAUL TO LAND FILL)
PRE-AERATION
FRESHENS WASTE WATER & HELPS REMOVE OIL
FLOW METER
MEASURES & RECORDS FLOW
PRIMARY TREATMENT
SEDIMENTATION AND FLOTATION
REMOVES SETTLEABLE & FLOATABLE MATERIALS
SECONDARY TREATMENT
SOLIDS HANDLING
TREATS SOLIDS REMOVED BY OTHER PROCESSES
ACTIVATED SLUDGE
REMOVES SUSPENDED & DISSOLVED SOLIDS
DISINFECTION
KILLS PATHOGENIC BACTERIA
EFFLUENT

Fig. 2.2 Flow diagram of a typical plant

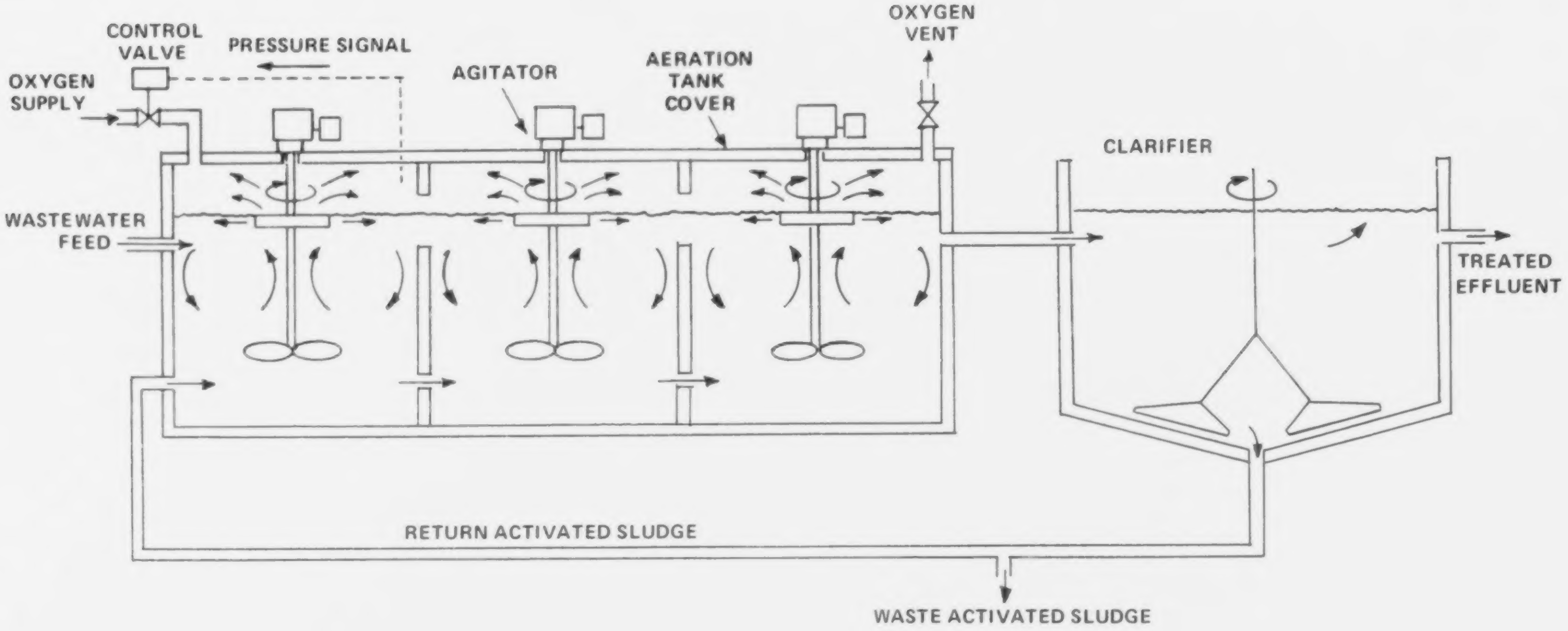
OXYGEN VENT
CONTROL VALVE
PRESSURE SIGNAL
OXYGEN SUPPLY
AGITATOR
AERATION TANK COVER
CLARIFIER
WASTEWATER FEED
TREATED EFFLUENT
RETURN ACTIVATED SLUDGE
WASTE ACTIVATED SLUDGE

Fig. 2.3 Schematic diagram of pure oxygen system with surface aerators (3 stages shown)

(Permission of Union Carbide Corporation)

When pure oxygen is driven into the water, it behaves similar to air and the bubbles rise to the water surface. During this rise to the surface, only a small portion of the oxygen is absorbed into the mixed liquor. Covering the reactor and sealing it from the outside atmosphere allows the oxygen that is not dissolved into the water (mixed liquor) to be used again. This contained gas over the water is still relatively high in oxygen concentration, the main contamination consisting of carbon dioxide gas given off by the respiration (breathing) of the activated sludge microorganisms and the nitrogen stripped from the incoming wastewater. The number of stages and the methods of contacting the liquid and oxygen vary from one system to another. In one type of design, the oxygen-rich gas that accumulates in the space between the mixed liquor water surface and the roof of the reactor is removed, compressed, and recycled back to the diffuser of the reactor. In another type of design, surface aerators are used to drive the oxygen-rich gas into the water. In deep reactors (40 feet or 12 m), the surface aerator device may also be equipped with an extended shaft and submerged impeller to keep the tank contents well mixed. A third type of design incorporates both submerged diffusers and surface aeration. Some reactors vent the excess oxygen along with the carbon dioxide. Uncovered reactors skim the surface sludge for wasting.

In all types of design, a valve opens automatically and admits more pure oxygen to the first-stage reactor whenever sufficient oxygen is removed from the gas space of the first-stage reactor to drop the pressure below the required 1 to 4 inches (2 to 10 cm) of water column pressure. This constantly replenishes the oxygen supply and the pressure is sufficient to force gas movement through the succeeding stages. This pressure prevents air from leaking into the reactors, diluting the oxygen concentration and possibly creating an explosive mixture. Oxygen leaking from a reactor can create an explosive condition on the roof or around the reactor. Potentially explosive conditions inside the reactor from a mixture of hydrocarbons and oxygen are avoided by an automatically activated analysis and purge system.

In each of the succeeding stages, the gas above the mixed liquid in that stage is reinjected into the mixed liquor of the same stage (by compressor or surface aerator). As the oxygen-rich gas passes from one stage to the next, the oxygen is used by the activated sludge microorganisms and the atmosphere becomes more and more diluted by the carbon dioxide produced by the organisms and nitrogen *STRIPPED*[3] from solution. The last stage in the reactor is equipped with a roof vent controlled by a valve mechanism that is called an oxygen vent valve. This valve vents gas from the last stage to the atmosphere and is normally set to vent gas when the oxygen concentration drops below 50 percent. As gas is vented from the last stage, more pure oxygen is released into the first stage to maintain the desired 1 to 4 inches (2 to 10 cm) of water column pressure.

Two methods are commonly used to produce pure oxygen. One is the **P**ressure **S**wing **A**bsorption (PSA) Oxygen Generating System and the other is the *CRYOGENIC*[4] Air Separation Method.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

2.1A Why are the pure oxygen reactors staged?

2.1B How is the pure oxygen diluted as it passes from one stage to the next stage?

2.11 PSA (Pressure Swing Absorption) Oxygen Generating System (Fig. 2.4)

The PSA Oxygen Generating Systems are usually installed in smaller plants. They take air from the atmosphere and compress it to 30 to 60 psi (2 to 4 kg/sq cm) and cool the compressed air in a water-cooled heat exchanger called an after cooler. The after cooler condenses and removes the moisture from the air stream. Next the air passes through an adsorbent vessel filled with a molecular sieve. Under pressure, this molecular sieve has the ability to adsorb nitrogen and other impurities from the atmospheric air, thus allowing the remaining pure oxygen to be used in the reactor. While one adsorber vessel is separating air into oxygen and nitrogen, the other two vessels are in various stages of desorption (or cleanup). The cleanup cycle consists of depressurizing and *PURGING*[5] with some product oxygen. The last step involves pressurizing with compressed air before going back on stream. During this process, product oxygen is flowing continuously to the activated sludge plant.

The PSA unit can be turned down to 25 percent of its rated oxygen throughout without a significant loss of efficiency. Compressor and valve maintenance can be scheduled so as not to have more than one or two days of downtime per year by the use of multiple compressors. A backup tank of liquid provides oxygen after evaporation to handle peak loads or downtime oxygen demand. The switching valves are selected on the basis of their ability to withstand very severe conditions over long periods of time.

2.12 Cryogenic Air Separation Method (Fig. 2.5)

Oxygen produced by the cryogenic air separation method uses low temperature (cryogenic) or refrigeration principles to separate oxygen from air. Air is filtered, compressed, cooled to remove moisture, and then routed to the cold box or "cryo" plant tower. These towers are heavily insulated to conserve energy by minimizing heat leaks or losses. In Fig. 2.5 all the items contained in the dash-lined box are located in the "cryo" plant tower.

The reversing heat exchanger primarily removes carbon dioxide and water. This heat exchanger has two directional gas flows; one of air going into the tower and the other of nitrogen being exhausted to the atmosphere. As the flowing air removes carbon dioxide and water, ice will form in the heat exchanger and restrict the air flow through the heat exchanger. After several minutes of operation, a valve is activated that interchanges the gas stream flows by reversing the direction of flow. The nitrogen exhaust is routed through the inlet air pas-

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[3] *Stripped Gases. Gases that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed or tumbled over media.*

[4] *Cryogenic (cry-o-JEN-nick). Low temperature.*

[5] *Purge. To remove a gas or vapor from a vessel, reactor or confined space.*

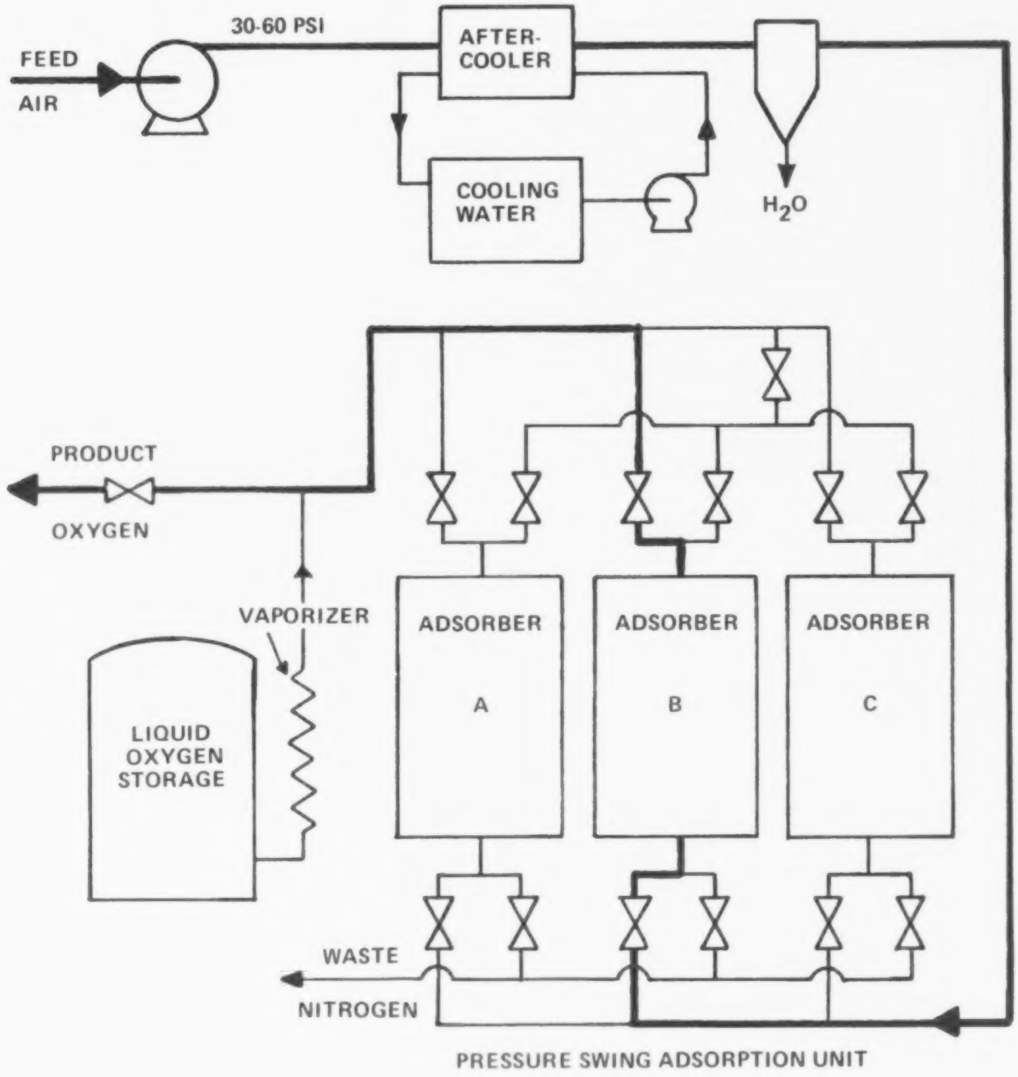
30-60 PSI
FEED
AIR
AFTER-
COOLER
COOLING
WATER
H_2O
PRODUCT
OXYGEN
VAPORIZER
LIQUID
OXYGEN
STORAGE
ADSORBER
A
ADSORBER
B
ADSORBER
C
WASTE
NITROGEN
PRESSURE SWING ADSORPTION UNIT

Fig. 2.4 Flow diagram of a three-bed PSA (Pressure Swing Adsorption) oxygen generating system

(Permission of Union Carbide Corporation)

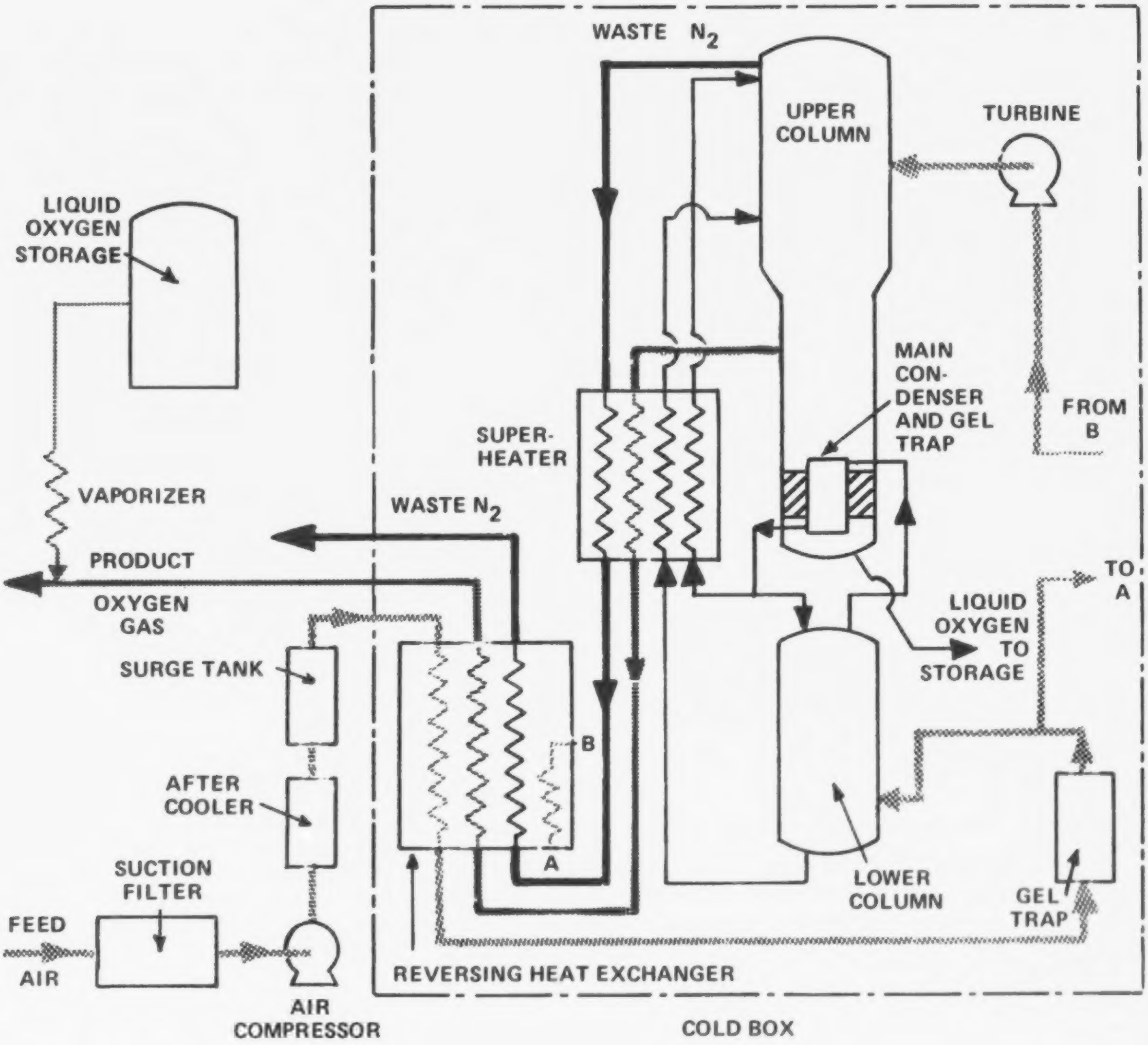
WASTE N_2
UPPER COLUMN
TURBINE
LIQUID OXYGEN STORAGE
MAIN CON-DENSER AND GEL TRAP
FROM B
SUPER-HEATER
VAPORIZER
WASTE N_2
PRODUCT
OXYGEN GAS
TO A
LIQUID OXYGEN TO STORAGE
SURGE TANK
B
AFTER COOLER
SUCTION FILTER
A
LOWER COLUMN
FEED AIR
GEL TRAP
REVERSING HEAT EXCHANGER
AIR COMPRESSOR
COLD BOX

Fig. 2.5 Flow diagram of a cryogenic oxygen generating system

(Permission of Union Carbide Corporation)

sage and thaws the partially blocked passages. A small portion of the water and carbon dioxide leave as tiny ice particles. The inlet air then travels through the previous nitrogen exhaust side until once again the ice builds up in the passage. Again the valve is activated and switches the routes of the two gas flows. This cycle usually varies from five to twenty minutes depending on the system. The exiting pure oxygen is also heat exchanged against the incoming air. In this case, however, the passages are never switched. This allows the oxygen to remain at high purity (about 98 percent pure oxygen).

A silica gel trap absorbs any remaining moisture that may have gotten past the reversing heat exchanger. Trace hydrocarbons are also picked up by the gel trap. The clean, cold air is liquified and separated into oxygen and nitrogen by fractional distillation in a two column arrangement. The lower high pressure column produces pure liquid nitrogen to use as reflux (flow back) in the low pressure upper column. Nitrogen, the most volatile component of air, is taken from the top of the upper column. Pure oxygen, the less volatile component, is taken from near the bottom of the upper column. A 98 percent purity oxygen stream is sent to the activated sludge process after heat exchange against the incoming air to recover its refrigeration (cool incoming air). Refrigeration to run the process comes from expanding a portion of the cooled and cleaned incoming air through an expansion turbine before it enters the upper column.

Approximately three percent of the capacity of the oxygen plant is available as liquid oxygen. This liquid can be used to keep the stored liquid oxygen backup tank full and ready to supply oxygen during peak loads or plant start-up.

To start an *AMBIENT TEMPERATURE*[6] cryogenic plant producing oxygen without liquid oxygen requires about three to five days. If liquid oxygen is available, a few hours is all that is required to place the plant in production. The oxygen production rate of a plant is determined by the oxygen demand in the activated sludge plant. As less production is required, the oxygen plant air compressors are partially unloaded.

Cryogenic plants are usually shut down once a year for approximately five to seven days for maintenance. During this period the gel traps are warmed to drive off moisture and hydrocarbons. By the use of multiple compressors and operational maintenance thaws, this downtime can be reduced to two or three days per year. During downtime, oxygen vaporized from the backup liquid oxygen storage tank is used. Sometimes in larger plants more than one oxygen producing facility is supplied to minimize the use of backup liquid oxygen.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

2.1C What two methods are commonly used to produce pure oxygen?

2.1D What does cryogenic mean?

2.1E How often and for how long are cryogenic plants shut down for maintenance?

2.13 Process and System Control

Pure oxygen systems may be used to supply oxygen to any of the activated sludge process modes — conventional, step-feed, complete mix or contact stabilization.

2.14 System Start-Up

Pure oxygen system start-up is basically much the same as starting conventional air systems. Individual components and starting procedures are usually outlined in the O&M manual or the manufacturer's literature. Take special care with the reactor because flow and organic loadings must be determined prior to start-up. Overloading or underloading may cause problems. Careful review of design data usually provides sufficient information to initially start the system. After start-up, the system is "fine tuned" to prevailing conditions in the wastewater.

2.15 Control Guidelines

1. *REACTOR VENT GAS* — A mixture of unused oxygen (about 5 to 10 percent of the oxygen supplied), inert gases and carbon dioxide is continually discharged from the last stage of the reactor. The vent purity, or percentage of oxygen contained in the mixture of gases, is an indicator of oxygen use efficiency. A low oxygen purity reading (25 percent or below) indicates that sufficient oxygen is not present and adequate BOD removal may not be accomplished. A high purity reading (50 percent or higher) indicates that too much oxygen is being wasted with the by-product gases. A manually controlled vent valve is adjusted to control vent purity. If purity is low, the valve could be opened further and closed down if purity is high. In normal operation (after start-up), "fine tuning" of this setting usually is not changed unless there is a drastic change in either the quantity or strength of the wastewater entering the plant.
2. *REACTOR GAS SPACE PRESSURE* — Gas space pressure is set by controlling the vent rate in the last stage. This will automatically establish the pressure level throughout the reactor. Gas pressure will vary to some extent within the reactor, dropping as more oxygen is vented and rising as venting is decreased or consumption is reduced. Pressure is usually preset at two inches (5 cm) water column in the first stage and the system will automatically feed oxygen at the required rates to maintain this condition. However, during high loading periods, the operator can increase oxygen transfer and production by increasing the pressure set point from 2 to 4 inches (5 to 10 cm) of water column, providing the vent valve setting is not changed. Relief valves on the first and last stage of each reactor prevent overpressurization. Similarly, during periods of unloading, a vacuum release provided by these same valves prevents a negative pressure.
3. *DISSOLVED OXYGEN* — A dissolved oxygen probe is sometimes located in the diversion box prior to the secondary clarifer or in the last stage of the reactor. It indicates the amount of DO in the mixed liquor. Typical oxygen systems usually operate with a DO range of 4 to 10 mg/*L* of dissolved oxygen. If the organic load increases over an extended period which would tend to drop the dissolved oxygen level below 4 mg/*L*, the operator should adjust the vent valve to a more open position which will increase oxygen production. Above a DO of 10 mg/*L*, the amount of oxygen being produced could be decreased if this is anticipated to be a long-term condition.

By measuring and monitoring these control guidelines, the operator can establish the most efficient treatment method on the basis of plant performance and experience. Operation of the secondary clarifiers, return rates, wasting rates and other control guidelines, are much the same for the pure oxygen system as they are for the conventional air activated sludge system.

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[6] *Ambient Temperature (Am-bee-ent). Temperature of the surroundings.*

2.16 Process Safety

Potentially explosive or flammable conditions can be present when pure oxygen gas is mixed with any hydrocarbon such as gasoline, fuel oil and lubricating oils. In addition to normal safety devices found on motors, compressors, electrical components and control mechanisms, the pure oxygen system uses safety devices to ensure process safety when working with oxygen gas. These safety devices are:

1. *L.E.L. (LOWER EXPLOSIVE LIMIT COMBUSTIBLE GAS DETECTOR)* — Indicates potential explosive conditions within the reactor, and analyzes samples collected from the first and last stage of each train in the reactor. Readings are made based on all components being analyzed as propane. If a hydrocarbon spill gets through the primary treatment system without being diverted and causes a reading of more than 25 percent of the L.E.L., an alarm will sound. The product valve from the oxygen system will shut down and air will automatically be directed to the reactor gas space to *PURGE*[7] the system. The purge will continue until normal readings are obtained. If the spill is so large that the L.E.L. continues to rise to the 50 percent level, in addition to an alarm sounding, an electrical restart of the purge blower will occur. The mixers will shut down to stop hydrocarbon stripping and they cannot be restarted until readings below the 10 percent L.E.L. are obtained.

   No electrical work is ever installed below the roof nor are there any metal-to-metal contact potentials present. The mixers pass through the roof through a water seal. This eliminates the potential for sparks and a source of ignition. By eliminating sources of ignition and any chance of ignitable mixtures, the chances of an explosion become virtually zero. To date the safety record at activated sludge plants using pure oxygen has been excellent. Also, having a deck (roof) over the reactor provides a safe and easily accessible place for maintenance work and further minimizes the chances of having accidents.

   One way to help prevent explosive conditions from developing is to install a Lower Explosive Limit (L.E.L.) Combustible Gas Detector in the plant headworks. This detector should trigger an alarm whenever hydrocarbons reach the headworks so action can be taken to prevent hydrocarbons from reaching reactors containing pure oxygen. Wastewater containing hydrocarbons can be diverted to emergency holding ponds if available.

2. *LIQUID OXYGEN (STORAGE TANK) LOW TEMPERATURE ALARM* — Provides an alarm and shutdown of the liquid storage system in the event heated water recirculation within the vaporizer reaches a low temperature level. A temperature monitor measures temperature levels of the oxygen gas and if the vapor falls below −10 degrees Fahrenheit (−23°C), an alarm will sound on the instrument panel. At an indication of −20 degrees Fahrenheit (−29°C), the liquid system will shut down until the temperature returns to normal conditions, but must be manually reset.

3. *EMERGENCY TRIP SWITCH* — In the event that any other unsafe condition should arise within the compressor system, liquid oxygen system or electrical panels, an emergency trip switch may be manually pulled. When pulled, the entire oxygen system shuts down and must be reset manually and each major piece of equipment restarted. This safety switch is not commonly used. It is only used as a last resort if safety systems fail or a major problem exists within the system which threatens the well being and the safety of personnel. This switch is usually located away from a source of danger. As with any treatment plant, the operator must follow safety precautions established by the manufacturers and design engineers. Caution and warning signs should be posted in areas where danger is present.

2.17 Operator Safety

Special safety rules must be applied when operating and maintaining pure oxygen systems because of the unique properties of high purity oxygen. Cold liquid oxygen (LOX) can cause skin burns. Always wear rubber gloves and protective clothing when taking liquid oxygen samples from columns. This is the only time operators need to handle liquid oxygen.

Pure oxygen supports and accelerates combustion more readily than air. Therefore, all types of hydrocarbons and other flammable materials must be kept from mixing with the oxygen. The following precautions are intended to eliminate the possibility of combustion and explosions.

1. Special non-hydrocarbon lubricants as specified by the manufacturer should be used for equipment in contact with oxygen.
2. Tools and equipment must be specially designed to be compatible for use in oxygen service.
3. Flammable materials must be kept far away from oxygen systems and storage tanks.
4. Grease and oil must be removed from tools and equipment by the use of a solvent such as chloroethane.
5. Smoking and open flames are prohibited near oxygen systems and storage tanks.

Liquid oxygen is delivered by specially designed trucks and transferred by specially trained technicians. Therefore, the chances of liquid oxygen spills are remote. If a liquid oxygen spill occurs, the liquid could saturate a combustible material and this material could ignite or explode. Ignition can be caused by hot objects, open flames, glowing cigarettes, embers, sparks, or impact such as might be caused by striking with a hammer, dropping a tool or scuffing with your heel. Typical combustible materials that are dangerous when saturated with spilled liquid oxygen include asphalt in black top pavements, humus in soil, oil or grease on concrete floors or pavements, articles of clothing, or *ANY OTHER SUBSTANCE THAT WILL BURN IN AIR.* Any equipment involving liquid oxygen should be constructed on a concrete pad to avoid the potential of soaking a black top surface with liquid oxygen.

Every possible effort must be made to prevent the spillage of liquid oxygen. If a spill does occur, the following procedures must be followed:

1. No one may set foot in any area still showing frost marks from an oxygen spill.
2. The affected area must be roped off as soon as possible. When rope, barricades and signs are not immediately available, someone must stay at the area to warn other persons of the hazard.
3. No tank car or truck movements are allowed over an area still showing frost marks from an oxygen spill.

These procedures apply to any oxygen spillage on any surface, including cement, gravel, black top, or dirt either inside buildings or outdoors. *NO ONE IS ALLOWED TO STEP ON ANY AREAS WHERE FROST MARKS EXIST FROM A SPILL.*

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[7] *Purge. Remove pure oxygen from the reactors and attempt to dilute hydrocarbon vapors to below the explosive limit.*

2.18 Pure Oxygen System Maintenance

Maintenance of a pure oxygen production system is specialized for the specific equipment. However, this equipment is similar to the equipment found in other types of activated sludge plants, including air compressors, valves and instruments. Manufacturers commonly aid the operator during start-up with training sessions and field work. A maintenance contract with the supplier can be used to provide the technical services needed. As with any large scale production system, equipment preventive maintenance ensures proper operation and greater efficiency.

QUESTIONS

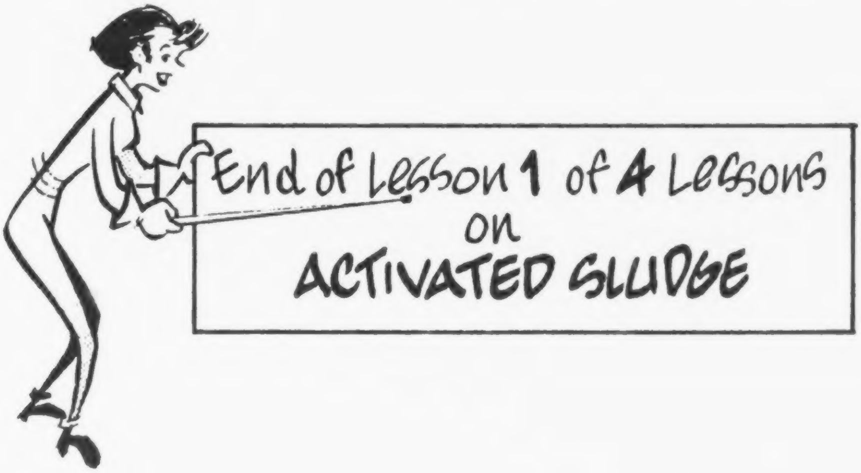
Write your answers in a notebook and then compare your answers with those on page 108.

2.1F What special measures are used to control pure oxygen systems?

2.1G How can hydrocarbons be detected before they reach the reactor?

2.19 Acknowledgment

This section was reviewed by Mr. R.W. Hirsch. The authors thank Mr. Hirsch for his many helpful comments and suggestions.


End of Lesson 1 of 4 Lessons
on
ACTIVATED SLUDGE

Please answer the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 1 of 4 Lessons)

Chapter 2. ACTIVATED SLUDGE

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. Why does the pure oxygen process normally use covered reactors?
2. How is pure oxygen separated from impurities and other gases in the PSA system?
3. What safety hazards might an operator encounter when working around a pure oxygen system?
4. What safety systems are found around pure oxygen systems to protect operators and equipment?

CHAPTER 2. ACTIVATED SLUDGE

(Lesson 2 of 4 Lessons)

NOTE: The next two lessons, Section 2.2, Return Activated Sludge, and Section 2.3, Waste Activated Sludge, are provided to familiarize you with different ways to control both the pure oxygen and air activated sludge processes. *YOU,* the operator, will have to determine which ways will work best for your plant. Once a particular procedure is selected, *EVERY OPERATOR ON EVERY SHIFT MUST FOLLOW THE SAME PROCEDURE.* If the procedure does not produce satisfactory results, then new procedures must be developed and tested for everyone to follow.

Abbreviations used in this section include:

1. MLSS, **M**ixed **L**iquor **S**uspended **S**olids, mg/*L*.
2. MLVSS, **M**ixed **L**iquor **V**olatile **S**uspended **S**olids, mg/*L*.
3. RAS, **R**eturn **A**ctivated **S**ludge, mg/*L*.
4. F/M, **F**ood to **M**icroorganism **R**atio, lbs BOD or COD added per day per lb of MLVSS or kg/day per kg MLVSS.
5. Q, Flow, MGD or cu m/sec.

2.2 RETURN ACTIVATED SLUDGE

2.20 Purpose of Returning Activated Sludge

To operate the activated sludge process efficiently, a properly settling mixed liquor must be achieved and maintained. The mixed liquor suspended solids (MLSS) are settled in a clarifier and then returned to the aeration tank as the Return Activated Sludge (RAS) (Fig. 2.6). The RAS makes it possible for the microorganisms to be in the treatment system longer than the flowing wastewater. For conventional activated sludge operations, the RAS flow is generally about 20 to 40 percent of the incoming wastewater flow. *CHANGES IN THE ACTIVATED SLUDGE QUALITY WILL REQUIRE DIFFERENT RAS FLOW RATES DUE TO SETTLING CHARACTERISTICS OF THE SLUDGE.* Table 2.1 shows typical ranges of RAS flow rates for some activated sludge process variations.

2.21 Return Activated Sludge Control

Two basic approaches that can be used to control the RAS flow rate are based on the following:

1. Controlling the RAS flow rate independently from the influent flow; and
2. Controlling the RAS flow rate as a constant percentage of the influent flow.

2.210 Constant RAS Flow Rate Control

Setting the RAS at a constant flow rate that is independent of the aeration tank influent wastewater flow rate results in a continuously changing MLSS concentration. The MLSS will be at a minimum during peak influent flows and at a maximum during low influent flows. This occurs because the MLSS are flowing into the clarifier at a higher rate during peak flow when they are being removed at a constant rate. Similarly, at minimum influent flow rates, the MLSS are returned to the aeration tank at a higher rate than they are flowing into the clarifier. The aeration tank and the secondary clarifier must be looked at as a system in which the MLSS are stored in the aeration tank during minimum wastewater flow and then transferred to the clarifier as the wastewater flows initially increase. In essence, the clarifier has a constantly changing depth of sludge blanket as the MLSS moves from the aeration tank to the clarifier and vice versa. The advantage of using this approach is simplicity, because it minimizes the amount of effort for control. This approach is especially effective for small plants with limited flexibility.

TABLE 2.1 A GUIDE TO TYPICAL RAS FLOW RATE PERCENTAGES[a]

Type of Activated Sludge Process	RAS Flow Rate as Percent of Incoming Wastewater Flow to Aeration Tank	
	Minimum	Maximum
Standard Rate	15	75
Carbonaceous Stage of Separate Stage Nitrification	15	75
Step-Feed Aeration	15	75
Contact Stabilization	50	150
Extended Aeration	50	150
Nitrification State of Separate Stage Nitrification	50	200

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[a] *RECOMMENDED STANDARDS FOR SEWAGE WORKS (10 STATE STANDARDS),* Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, 1978 Edition, published by Health Education Service, Post Office Box 7126, Albany, New York 12224. Price, $1.75 plus 48¢ for shipping and handling charges.

2.211 Constant Percentage RAS Flow Rate Control

The second approach to controlling RAS flow rates requires a programmed method for maintaining a constant percentage of RAS flow to the aeration tank influent wastewater flow rate. The program may consist of an automatic flow-measurement device, a programmed system, or frequent manual adjustments. The programmed method is theoretically designed to keep the MLSS more constant through high and low flow periods.

2.212 Comparison of Both RAS Control Approaches

The advantages of the constant RAS flow approach are the following:

1. Simplicity.
2. Maximum solids loading on the clarifier occurs at the start of peak flow periods.
3. Requires less operational time.

The advantages of the constant percentage RAS flow approach are the following:

1. Variations in the MLSS concentration are reduced and the F/M ratio varies less.
2. The MLSS will remain in the clarifier for shorter time periods which may reduce the possibility of denitrification in the clarifier.

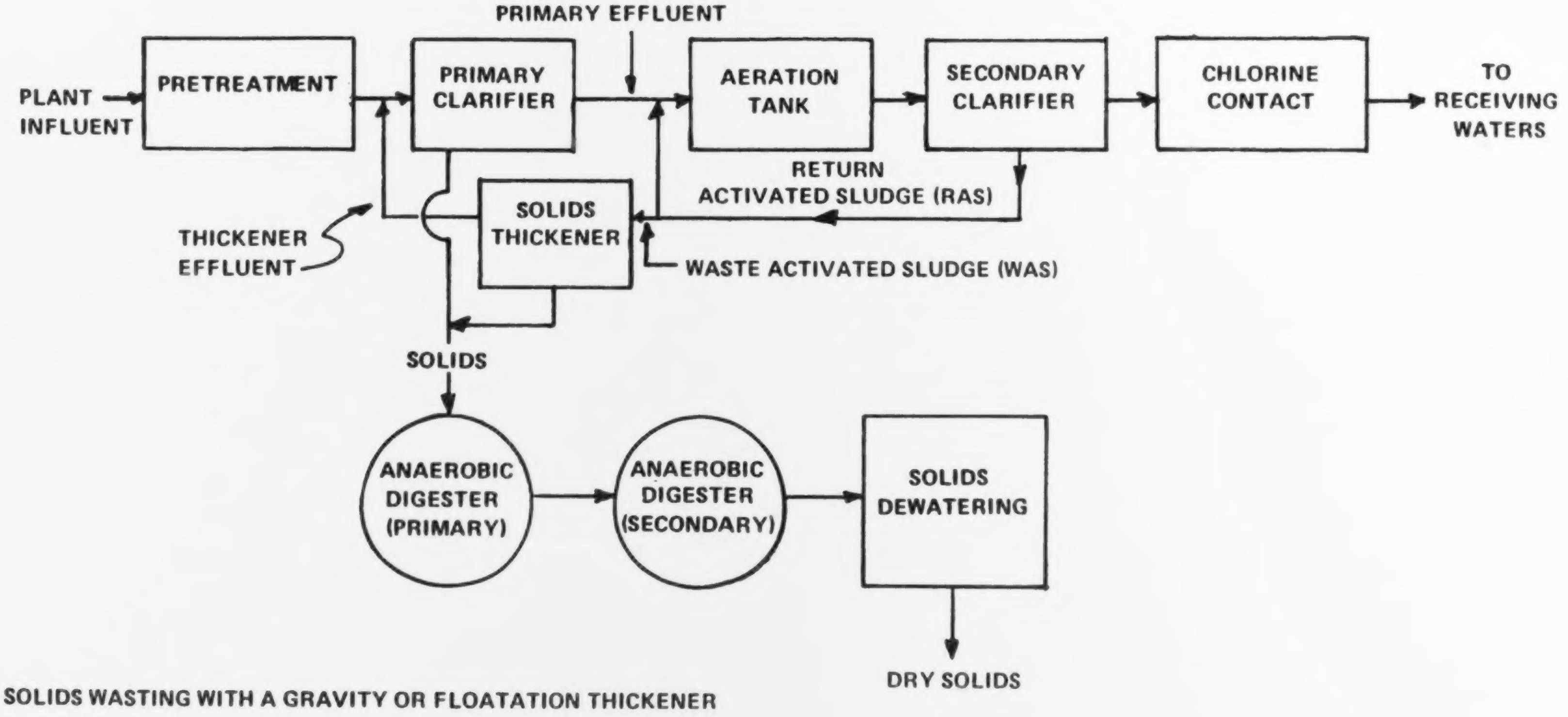
PRIMARY EFFLUENT
PLANT INFLUENT
PRETREATMENT
PRIMARY CLARIFIER
AERATION TANK
SECONDARY CLARIFIER
CHLORINE CONTACT
TO RECEIVING WATERS
RETURN ACTIVATED SLUDGE (RAS)
SOLIDS THICKENER
THICKENER EFFLUENT
WASTE ACTIVATED SLUDGE (WAS)
SOLIDS
ANAEROBIC DIGESTER (PRIMARY)
ANAEROBIC DIGESTER (SECONDARY)
SOLIDS DEWATERING
DRY SOLIDS
SOLIDS WASTING WITH A GRAVITY OR FLOATATION THICKENER

Fig. 2.6 Return and waste activated sludge flow diagram

A limitation of using the constant flow approach is that the F/M ratio is constantly changing. The range of F/M fluctuation due to short-term variations in the MLSS (because of hydraulic loading) is generally small enough so that no significant problems arise.

The most significant limitation of the constant percentage flow approach is that the clarifier is subjected to maximum hydraulic loading when the reactor contains the maximum amount of sludge. This may result in solids washout with the secondary effluent.

In general, it appears that most activated sludge operations perform well and require less attention when the constant RAS flow rate approach is used. In many plants it is much simpler for the operator to let the MLSS fluctuate, as long as adequate treatment can be maintained. Larger, more complex plants may have to vary the RAS to keep the MLSS close to the target value. Activated sludge plants with flows of 10 MGD (37,850 cu m/day) or less often experience large hydraulic surges and performance of these plants will benefit the most from the use of the constant RAS flow rate approach.

Procedures for monitoring and maintaining RAS flow rates are presented in Table 2.2. The operator may develop detailed standard operating procedures for treatment plants by using this table.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

2.2A What words do the letters in the following abbreviations represent?

1. MLSS
2. MLVSS
3. RAS
4. F/M

2.2B What are the two basic approaches that can be used to control the RAS flow rate?

2.22 Methods of RAS Flow Rate Control

For either RAS flow rate control approach discussed above, there are a number of techniques which may be used to set the rate of sludge return flow. The most commonly used techniques are listed below:

1. Monitoring the depth of the sludge blanket.
2. Settleability approach, and
3. SVI approach.

2.220 Sludge Blanket Depth

Monitoring the depth of the sludge blanket in the clarifier is the most direct method available for determining the RAS flow rate. The sludge blanket depth and uniformity may be checked by any of the following methods:

1. A series of air lift pumps mounted within the clarifier at various depths;
2. Gravity flow tubes located at various depths;
3. Electronic sludge level detector (a light source and photo-electric cell attached to a graduated handle or drop cord. The photo-electric cell actuates a buzzer when in contact with the sludge);
4. Sight glass finder (a graduated pipe with a light source and sight glass attached to the lower end);
5. Plexiglass core sampler; and
6. Some type of portable pumping unit with a graduated suction pipe or hose (siphon).

The blanket depth should be kept from one to three feet (0.3 to 1 m) as measured from the clarifier bottom at the sidewall. The operator must check the blanket depth on a routine basis, making adjustments in the RAS to control the blanket depth.

If it is observed that the depth of the sludge blanket is increasing, however, an increase in the RAS flow can only solve the problem on a short-term basis. Increases in sludge blanket depth may result from having too much activated sludge in the treatment system, and/or because of a poorly settling sludge. Long-term corrections must be made that will improve the settling characteristics of the sludge or remove the excess solids from the treatment system. If the sludge is settling poorly, increasing the RAS flow may even cause more problems by further increasing the flow through the clarifier. If the sludge is settling poorly due to bulking, the environmental conditions for the microorganisms must be improved. If there is too much activated sludge in the treatment system, the excess sludge must be wasted.

Measurements of the sludge blanket depth in the clarifier should be made at the same time each day. The best time to make these measurements is during the period of maximum daily flow because the clarifier is operating under the highest solids loading rate. The sludge blanket should be measured daily, and adjustments to the RAS rate can be made as necessary. Adjustments in the RAS flow rate should only be needed occasionally if the activated sludge process is operating properly.

An additional advantage of monitoring the sludge blanket depth is that problems, such as improperly operating sludge collection equipment, will be observed due to irregularities in the blanket depth. A plugged pickup on a clarifier sludge collection system would cause sludge depth to increase in the area of the pickup and decrease in the areas where the properly operating pickups are located. These irregularities in sludge blanket depth are easily monitored by measuring profiles of blanket depth across the clarifier.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

2.2C The sludge blanket depth should be kept to less than what portion or fraction of the clarifier sidewall water depth?

2.2D When should the sludge blanket depth be measured and why?

2.221 Settleability Approach

Another method of calculating the RAS flow rate is based on the results of the 30-minute settling test. Settleability is defined as the percentage of volume occupied by the sludge after settling for 30 minutes. Test is run on a sample collected from the aeration basin effluent.

EXAMPLE

Determine the return activated sludge (RAS) flow as a percentage of the influent flow and in MGD when the influent flow is 7.5 MGD (28,390 cu m/day) and the sludge settling volume (SV) in 60 minutes is 275 ml/*L*.

Known		**Unknown**
Infl. Flow, MGD	= 7.5 MGD	1. RAS Flow as a Percent of Infl. Flow, %
Sl Set Vol. (SV), ml/*L*	= 275 ml/*L*	2. RAS Flow, MGD

TABLE 2.2 STANDARD OPERATING PROCEDURES FOR RAS CONTROL

PROCESS	RAS CONTROL METHOD	MODE OF OPERATION	WHAT TO CHECK	FREQUENCY OF ADJUSTMENT	WHEN TO CHECK	CONDITION	PROBABLE CAUSE	RESPONSE
Complete Mix or Plug Flow	Constant Flow	Manual	Sludge Blanket	Daily	Every 8 Hours	High	Low RAS Rate	Increase Return
						Satisfactory	—	Continued Monitoring
						Low	High RAS Rate	Decrease Return
	Constant % of Influent Flow	Manual	% of Influent Flow	2 Hrs	Every 2 Hrs	High Satisfactory Low	Variations in Daily Influent Flow	Adjust to Desired % of Influent Flow
			Sludge Blanket	Daily	Every 8 Hrs	High	% of Flow Too Low	Increase % of Flow
						Satisfactory	—	Continue Monitoring
						Low	% of Flow Too High	Decrease % of Flow
	Constant % of Influent Flow	Automatic	Sludge Blanket	Daily	Every 8 Hrs	High	% of Flow Too Low	Increase % of Flow
						Satisfactory	—	Continue Monitoring
						Low	% of Flow Too High	Decrease % of Flow
	Control by Sludge Blanket Level	Automatic	Sludge Blanket	Daily	Every 8 Hrs	High or Low	Controller Malfunction	Fix Controller or Manually Adjust Accordingly
						Satisfactory	—	Continue Monitoring
Reaeration or Contact Stabilization	Constant % of Flow	Automatic	Ratio of $MLSS/RAS_{SS}$ (Centrifuge Test)	Every 2 Hrs	Every 2 Hrs	High Ratio	Return Too High	Decrease Return
						Satisfactory	—	Continue Monitoring
						Low Ratio	Return too Low	Increase Return

1. Calculate RAS flow as a % of influent flow.

$$\text{RAS Flow, \%} = \frac{\text{SV, ml}/L \times 100\%}{1{,}000 \text{ ml}/L - \text{SV, ml}/L}$$

$$= \frac{275 \text{ ml}/L \times 100\%}{1{,}000 \text{ ml}/L - 275 \text{ ml}/L}$$

$$= \frac{275 \text{ ml}/L \times 100\%}{725 \text{ ml}/L}$$

$$= 38\% \text{ of influent flow rate}$$

2. Calculate RAS Flow, MGD.

$$\text{RAS Flow, MGD} = \text{RAS Flow, decimal} \times \text{Infl. Flow, MGD}$$

$$= 0.38 \times 7.5 \text{ MGD}$$

$$= 2.8 \text{ MGD} \times 694 \text{ GPM/MGD}^{*}$$

$$= 1{,}945 \text{ GPM}$$

The settleability method assumes that measurements made with a laboratory settling cylinder will accurately reflect the settling in a clarifier. This assumption will seldom (if ever) be true because of the effects of the cylinder walls and the quiescent (still or lack of turbulence) nature of the liquid in the cylinder. Some operators have found that gently stirring (1-2 rpm) the sludge during the settling test reduces these problems.

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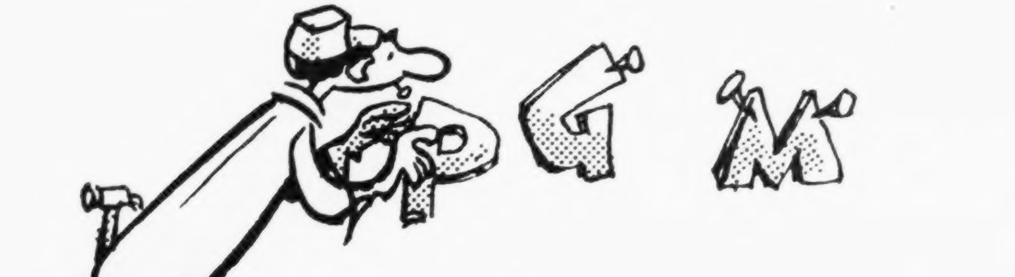
* This is a factor for converting MGD to GPM.



Another way to calculate the RAS flow as a percentage of the influent flow is by using the chart in Fig. 2.7 below. First, locate the SV value (from the 60-minute sludge settling test — 275 ml/*L*) on the bottom scale. Draw a vertical line up to the curve and a horizontal line from that point to the left vertical axis. The value (38%) is the RAS flow as a percentage of the influent flow. To find the RAS flow in MGD, multiply the R/Q value (0.38) by Q (7.5 MGD).

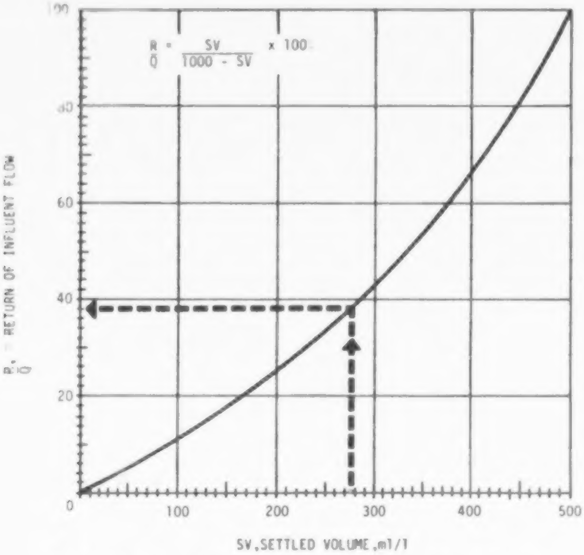


Fig. 2.7 Chart for calculating return sludge flow

2.222 SVI[8] Approach

To determine the RAS flow rate using the Sludge Volume Index (SVI), it is necessary to include the settleability approach. Therefore, this method is subject to the same limitations as the settleability method.

As you can see by the following example, the SVI method uses the Sludge Volume Index to estimate the suspended solids concentration of the return activated sludge (RAS). In calculation #1, RAS Suspended Solids = 8,333 mg/*L*. This value (8,333 mg/*L*) is then used to find the RAS flow rate (calculation #2; 2.4 MGD). Next, the RAS flow as a percentage of influent flow (calculation #3 in the example; 32%)

EXAMPLE

Determine the return activated sludge (RAS) flow in MGD and as a percentage of influent flow when the influent flow is 7.5 MGD (28,390 cu m/day), the mixed liquor suspended solids (MLSS) are 2,000 mg/*L* and the SVI is 120.

Known		**Unknown**
Infl. Flow, MGD	= 7.5 MGD	1. RAS Flow, MGD
MLSS, mg/*L*	= 2,000 mg/*L*	2. RAS Flow as a percent of Infl. Flow, %
SVI	= 120	

1. *Calculate the RAS suspended solids based on the SVI.*

$$\text{RAS Susp. Sol., mg/}L = \frac{1{,}000{,}000}{\text{SVI}} = \frac{1{,}000{,}000}{120} = 8{,}333 \text{ mg/}L$$

2. Calculate RAS Flow, MGD, based on SVI.

$$\text{RAS Flow, MGD} = \frac{\text{Infl. Flow, MGD} \times \text{MLSS, mg/}L}{\text{RAS Susp. Sol., mg/}L - \text{MLSS, mg/}L}$$
$$= \frac{7.5 \text{ MGD} \times 2{,}000 \text{ mg/}L}{8{,}333 \text{ mg/}L - 2{,}000 \text{ mg/}L}$$
$$= \frac{15{,}000 \text{ MGD} \cdot \text{mg/}L}{6{,}333 \text{ mg/}L}$$
$$= 2.4 \text{ MGD}$$

3. Calculate the RAS flow as a % of influent flow.

$$\text{RAS Flow, \%} = \frac{\text{RAS Flow, MGD} \times 100\%}{\text{Infl. Flow, MGD}} = \frac{2.4 \text{ MGD} \times 100\%}{7.5 \text{ MGD}} = 32\% \text{ of influent flow}$$

The real value in the SVI is not in calculating the RAS flow, but in its use as a process stability indicator. Changes in the SVI at a constant MLSS are more important than the SVI value. Never be concerned too much about comparing the SVI of different treatment plants because the SVI value that indicates good operation in one plant may not necessarily apply to good operation in other plants. In general, typical pure oxygen activated sludge plants have SVIs from 50 to 100 and air activated sludge plants have SVIs from 100 to 300.

2.23 Return Rates with Separate Sludge Reaeration

In the sludge reaeration (contact stabilization) variation of the activated sludge process, the return sludge rate is much more significant. This is true because the rate of return directly affects the ratio of sludge concentration between the contact portion of the process and the stabilization or reaeration portion. Generally, a higher rate of return will shift solids from the stabilization portion of the process to the contact portion of the process. Adequate theories for making rational adjustments of the contact/stabilization ratio are just becoming available, and, at this point, the operator must depend on crude rules of thumb or on operating experience to determine which levels are appropriate. These rules of thumb include the following:

1. The suspended solids concentration in the reaeration portion will eventually equal the RAS suspended solids concentration. Therefore, the RAS flow rate should be controlled on the basis of maintaining the desired suspended solids concentration in the re-aeration portion of the process.

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[8] *Sludge Volume Index (SVI). This test is used to indicate the settling ability of activated sludge (aerated solids) in the secondary clarifier. The test is a measure of the volume of sludge compared with its weight. Allow the sludge sample from the aeration tank to settle for 30 minutes. Then calculate SVI by dividing the volume (ml) of wet settled sludge by the weight (mg) of that sludge after it has been dried. Sludge with an SVI of one hundred or greater will not settle as readily as desirable because it is as light as or lighter than water.*

$$SVI = \frac{\text{Wet Settled Sludge, ml}}{\text{Dried Sludge Solids, mg}} \times 1000$$

TABLE 2.3 *EFFECTS OF CHANGES ON RETURN SLUDGE AERATION TIME (RSAT)*

PROCESS CONTROL GUIDELINES	CHANGE MADE		EFFECT ON SVI		EFFECT ON NITRIFICATION	
			Increase	Decrease	Increase	Decrease
Step Change	Increase RSAT			•		•
	Decrease RSAT		•		•	
Return Sludge Flow	Increase		•			•
	Decrease			•	•	
Process Air Rate (D.O.)	Increase			•	•	
	Decrease		•			•
Plant Loading lb. COD or BOD per lb. total plant MLVSS	Increase	Increase Plant Q	•			•
		Decrease MCRT				•
	Decrease	Decrease Plant Q		•	•	
		Increase MCRT			•	

NOTE:

1. Changes made in the aeration system are reflected in the secondary clarifiers by how well the sludge settles.
2. When making a process change you must consider what changing one control guideline does to the others.

EXAMPLE: a. An increase in the return sludge flow will decrease the Return Sludge Aeration Time (RSAT).
b. An increase in the process air rate is like increasing the RSAT.
c. An increase in plant Q can result in a return sludge increase.
d. An increase in the return sludge flow can cancel a step change that was made to increase the RSAT.

2. The contact portion suspended solids concentration may be determined by the following formula:

$$\text{Contact MLSS, mg}/L = \frac{\text{RAS Flow, MGD} \times \text{RAS Susp. Sol., mg}/L}{\text{Infl. Flow, MGD} + \text{RAS Flow, MGD}}$$

3. RAS flow may be determined by the following formula:

$$\text{RAS Flow, MGD} = \frac{\text{Infl. Flow, MGD} \times \text{MLSS, mg}/L}{\text{RAS Susp. Sol., mg}/L - \text{MLSS, mg}/L}$$

4. If the SVI remains constant or begins to drop, it indicates that the solids inventory in the process may be too high and wasting should be increased. If the SVI increases in conjunction with a rising sludge blanket in the clarifier, sludge bulking may occur. Refer to Table 2.3 for some suggested solutions under these conditions.

2.24 Acknowledgement

This section was adapted from *PROCESS CONTROL MANUAL FOR AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES,* Municipal Operations Branch, Office of Water Program Operations, Washington, D.C. 20460.

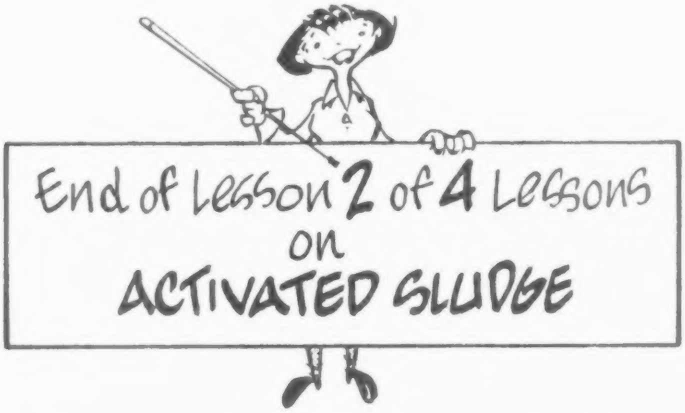
QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 108 and 109.

2.2E What techniques are used to determine the rate of RAS flow?

2.2F How long is the sludge allowed to settle in the settleability test?

2.2G Calculate the return activated sludge (RAS) flow rate in MGD when the influent flow is 4 MGD and the sludge settling volume (SV) in 30 minutes is 250 ml.


End of Lesson 2 of 4 Lessons
on
ACTIVATED SLUDGE

Please answer the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 4 Lessons)

Chapter 2. ACTIVATED SLUDGE

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 2.

5. What are the advantages of the constant RAS flow approach and the constant percentage RAS flow approach?
6. Different RAS flow rates will be required as the result of what two activated sludge conditions?
7. What is the difference between the method of RAS control and the rate of RAS control?
8. Why is the following statement true and how can this problem be corrected on a long-term basis? If you observe that the depth of the sludge blanket is increasing, an increase in the RAS flow can only solve the problem on a short-term basis.

CHAPTER 2. ACTIVATED SLUDGE

(Lesson 3 of 4 Lessons)

Abbreviations used in this section include:

1. RAS, **R**eturn **A**ctivated **S**ludge
2. WAS, **W**aste **A**ctivated **S**ludge
3. MCRT, **M**ean **C**ell **R**esidence **T**ime
4. MLVSS, **M**ixed **L**iquor **V**olatile **S**uspended **S**olids

2.3 WASTE ACTIVATED SLUDGE

2.30 Purpose of Wasting Activated Sludge

One of the most important controls of the activated sludge process is the amount of activated sludge that is wasted. The amount of waste activated sludge (WAS) removed from the process affects all of the following items:

1. Effluent quality,
2. Growth rate of the microorganisms,
3. Oxygen consumption,
4. Mixed liquor settleability,
5. Nutrient quantities needed,
6. Occurrence of foaming/frothing, and
7. Possibility of nitrifying.

The objective of wasting activated sludge is to maintain a balance between the microorganisms under aeration and the amount of incoming food as measured by the COD or BOD test. When microorganisms remove BOD from wastewater, the amount of activated sludge increases (microorganisms grow and multiply). The rate at which these microorganisms grow is called the growth rate and is defined as the increase in the amount of activated sludge that takes place in one day. The objective of sludge wasting is to remove just the amount of microorganisms that grow in excess of the microorganism death rate. When this is done, the amount of activated sludge formed by the microorganism growth is just balanced by that which is removed from the process. This allows the total amount of activated sludge in the process to remain somewhat constant. This condition is called "steady-state" and is a desirable condition for operation. However, "steady-state" can only be approximated because of the variations in the nature and quantity of the food supply (BOD) and of the microorganism population. The objective of process control is to approach a particular "steady-state" by controlling any one or a combination of the following control guidelines.

1. Sludge Age
2. F/M or Food to Microorganism Ratio
3. MCRT, Mean Cell Residence Time
4. Volatile Solids Inventory
5. MLVSS Concentration

The best mode of process control will produce a high quality effluent which meets NPDES permit requirements with consistent treatment results at a minimal cost.

Wasting of the activated sludge (Fig. 2.6, page 54) is usually achieved by removing a portion of the RAS flow. The waste activated sludge is either pumped to thickening or dewatering facilities and then to a digester or incinerator, or

MLVSS CONCENTRATION

to the primary clarifiers where it is pumped to digester with the raw sludge. Procedures for making WAS adjustments are presented in Table 2.4 which the operator may use to develop standard operating procedures for a treatment plant.

An alternate method for wasting sludge is taking it from the mixed liquor in the aeration tank. There are much higher concentrations of suspended matter in the RAS than there are in the mixed liquor. Therefore, when wasting is practiced from the aeration tank, larger sludge handling facilities are required. Wasting from the RAS takes advantage of the gravity settling and thickening of the sludge that occurs in the secondary clarifier. However, wasting from the aeration tank has the advantage of not wasting excessive amounts of sludge since a large quantity of mixed liquor is involved. The extra security of wasting from the aeration tank should not be underestimated. Unfortunately, many plants do not have the flexibility to waste from the aeration tank nor are there sufficient sludge handling facilities to handle the more dilute sludge.

2.31 Methods of Sludge Wasting

Wasting of the activated sludge can be accomplished on an intermittent or continuous basis. The intermittent wasting of sludge means that wasting is conducted on a batch basis from day to day.

2.310 Sludge Age Control

Sludge age is a measure of the length of time a particle of suspended solids has been undergoing aeration in the activated sludge process. As you can see in this formula for calculating sludge age, it is based on a ratio between the solids in the aeration tank and the solids in the incoming wastewater.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids Under Aeration, lbs or kg}}{\text{Suspended Solids Added, lbs/day or kg/day}}$$

Using sludge age as a control technique, the operator wastes just enough sludge to maintain the sludge age which produces the best quality effluent. In most activated sludge plants, sludge age ranges from 3 to 8 days. Difficulties are commonly experienced using the sludge age control technique when the BOD or COD to solids ratio in the wastewater changes. This is because sludge age is based on the assumption that the BOD (or COD)/solids ratio is fairly constant. By realizing that the BOD or COD to solids ratio does change and adjusting the sludge age when the ratio changes, the sludge age is a useful process control technique. Calculate the sludge age as shown in the following example.

EXAMPLE

Determine the sludge age for an activated sludge plant with an influent flow of 7.5 MGD (28,390 cu m/day). The primary effluent suspended solids concentration is 100 mg/*L*. Two aeration tanks have a volume of 0.6 MG (2,270 cu m) each and a mixed liquor suspended solids (MLSS) concentration of 2,200 mg/*L*.

Known		**Unknown**
Infl. Flow, MGD	= 7.5 MGD	Sludge Age, days
Prim. Effl. SS, mg/*L*	= 100 mg/*L*	
Tank Vol., MG	= 0.6 MG/tank	
MLSS, mg/*L*	= 2,200 mg/*L*	
No. of tanks	= 2 tanks	

TABLE 2.4 STANDARD OPERATING PROCEDURES FOR WAS CONTROL

METHOD OF CONTROL	PROCESS OPERATION	WHAT TO CHECK	WHEN TO CHECK	CALCULATIONS	FREQUENCY OF ADJUSTMENT	CONDITIONS	PROBABLE CAUSE	RESPONSE[a]
F/M	HIGH RATE	MLVSS & INFLUENT COD	DAILY	F/M BASED ON- $\frac{\text{7 DAY AVG. COD}}{\text{7 DAY AVG. MLVSS}}$	DAILY	ACTUAL F/M: HIGH	EXCESSIVE WASTING	REDUCE WAS
	CONVENTIONAL RATE					SATISFACTORY	—	
	EXTENDED AERATION					LOW	INSUFFICIENT WASTING	INCREASE WAS
MLVSS	HIGH RATE	MLVSS & INFLUENT COD OR BOD	DAILY	VOLATILE SOLIDS INVENTORY	DAILY	ACTUAL MLVSS: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE					SATISFACTORY	—	
	EXTENDED AERATION					LOW	EXCESSIVE WASTING	REDUCE WAS
MCRT	HIGH RATE	MLSS, WAS_{ss}, Q_{was}, & $EFFL_{ss}$	DAILY	7 DAY AVG[b] SOLIDS INVENTORY	DAILY	ACTUAL MCRT: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE			7 DAY AVERAGE[b] OF SOLIDS IN WAS		SATISFACTORY	—	
	EXTENDED AERATION			7 DAY AVERAGE[b] OF SOLIDS IN EFFLUENT		LOW	EXCESSIVE WASTING	REDUCE WAS
SLUDGE AGE	HIGH RATE	INFLUENT SS, & MLSS	DAILY	7 DAY AVG OF SS INVENTORY & SS IN INFLUENT	DAILY	ACTUAL SA: HIGH	INSUFFICIENT WASTING	INCREASE WAS
	CONVENTIONAL RATE					SATISFACTORY	—	
	EXTENDED AERATION					LOW	EXCESSIVE WASTING	REDUCE WAS

[a] Response - Calculations should be made to determine the WAS rate. However, when increasing or decreasing daily WAS rates, any changes should not exceed 10 to 15 percent of the previous day's WAS rate. This is necessary to allow the process to stabilize.

[b] When calculating the MCRT, determine the desired MCRT (7 days) and use the moving average for the number of days (7 days) in the desired MCRT.

$$\text{Sludge Age, days} = \frac{\text{Solids under aeration, lbs}}{\text{Solids added, lbs/day}}$$

1. Calculate the solids under aeration, lbs.

$$\begin{aligned}\text{Solids under aeration, lbs} &= \text{No Tanks} \times \text{Tank Vol. MG/tank} \times \text{MLSS, mg/}L \times 8.34\ \text{lbs/gal}\\ &= 2\ \text{tanks} \times 0.6\ \text{MG/tank} \times 2200\ \text{mg/}L \times 8.34\ \text{lbs/gal}\\ &= 22{,}000\ \text{lbs}\end{aligned}$$

2. Calculate the solids added, lbs/day

$$\begin{aligned}\text{Solids added, lbs/day} &= \text{Infl. Flow, MGD} \times \text{Prim. Effl. SS, mg/}L \times 8.34\ \text{lbs/gal}\\ &= 7.5\ \text{MGD} \times 100\ \text{mg/}L \times 8.34\ \text{lbs/gal}\\ &= 6{,}255\ \text{lbs/day}\end{aligned}$$

3. Determine sludge age, days.

$$\begin{aligned}\text{Sludge Age, days} &= \frac{\text{Solids under aeration, lbs}}{\text{Solids added, lbs/day}}\\ &= \frac{22{,}000\ \text{lbs}}{6{,}255\ \text{lbs/day}}\\ &= 3.5\ \text{days}\end{aligned}$$

Calculate the waste activated sludge (WAS) flow rate using the sludge age control technique as shown in the following example.

EXAMPLE

Determine the waste activated sludge (WAS) flow rate in MGD for an activated sludge plant that adds 6,255 lbs (2,837 kg) of solids per day (from previous problem). The solids under aeration are 33,075 pounds (15,000 kg), the return activated sludge (RAS) suspended solids concentration is 6,300 mg/*L* and the desired sludge age is 5 days. Current sludge waste rate is 4,455 lbs (2,020 kg) per day.

Known		Unknown
Solids Added, lbs/day	= 6,255 lbs/day	WAS Flow, MGD
Solids Aerated, lbs	= 33,075 lbs	
RAS Susp. Sol., mg/*L*	= 6,300 mg/*L*	
Desired Sludge Age, days	= 5 days	
Current WAS Rate, lbs/day	= 4,455 lbs/day	

1. Calculate the desired pounds of solids under aeration (MLSS) for the desired sludge age of 5 days.

$$\begin{aligned}\text{Desired Solids under aeration, lbs} &= \text{Solids Added, lbs/day} \times \text{Sludge Age, days}\\ &= 6{,}255\ \text{lbs/day} \times 5\ \text{days}\\ &= 31{,}275\ \text{lbs}\end{aligned}$$

2. Calculate the additional WAS flow, MGD, to maintain the desired sludge age.

$$\begin{aligned}\text{Additional WAS FLOW, MGD} &= \frac{\text{Solids Aerated, lbs} - \text{Desired Solids, lbs}}{\text{RAS Susp. Sol., mg/}L \times 8.34\ \text{lbs/gal}}\\ &= \frac{33{,}075\ \text{lbs} - 31{,}275\ \text{lbs}}{6{,}300\ \text{mg/}L^{*} \times 8.34\ \text{lbs/gal}}\\ &= \frac{1{,}800\ \text{lbs removed per day}^{**}}{52{,}542}\\ &= 0.034\ \text{MGD}^{***} \times 694\ \text{GPM/MGD}\\ &= 24\ \text{GPM}\end{aligned}$$

3. Add the current WAS flow to the additional WAS flow, MGD.

$$\begin{aligned}\text{Total WAS Flow, MGD} &= \text{Current WAS Flow, MGD} + \text{Additional WAS Flow, MGD}\\ &= \frac{\text{Solids Wasted, lbs/day}}{\text{RAS Susp. Sol., mg/}L \times 8.34\ \text{lbs/gal}} + \text{Flow, MGD}\\ &= \frac{4{,}455\ \text{lbs/day}}{6{,}300\ \text{mg/}L \times 8.34\ \text{lbs/gal}} + 0.034\ \text{MGD}\\ &= 0.085\ \text{MGD} + 0.034\ \text{MGD}\\ &= 0.119\ \text{MGD} \times 694\ \text{GPM/MGD}\\ &= 82\ \text{GPM}\end{aligned}$$

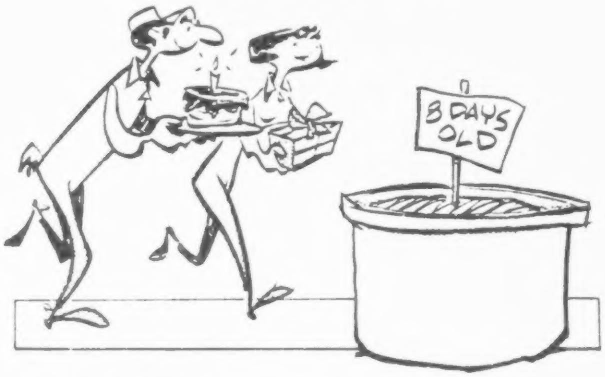
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

2.3A What is the objective of wasting activated sludge?

2.3B How is wasting of the excess activated sludge usually achieved?

2.3C Calculate the waste activated sludge (WAS) flow rate in MGD and GPM for an activated sludge plant that adds 4,750 lbs of solids per day. The solids under aeration are 41,100 pounds and the return activated sludge (RAS) suspended solids concentration is 5,800 mg/*L*. The desired sludge age is 8 days.



2.311 F/M Control

F/M control is used to ensure that the activated sludge process is being loaded at a rate that the microorganisms in the mixed liquor volatile suspended solids (MLVSS) are able to use most of the food supply in the wastewater being treated. If too much or too little food is applied for the amount of microorganisms, operating problems may occur and the effluent quality may drop.

There are four facts that should be remembered regarding the F/M method of control:

1. The food concentration is estimated with the COD (or BOD) tests. The oxygen demand tests provide crude but reliable approximations of the actual amount of food removed by the microorganisms.
2. The amount of food (COD or BOD) applied is important to calculate the F/M.
3. The quantity of microorganisms can be represented by the quantity of MLVSS. Ideally, the living or active microorganisms would simply be counted, but this is not feasible, and studies have shown that the MLVSS is a good approximation of the microorganisms concentrations in the MLSS.

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* Remember that mg/*L* is the same as lbs/M lbs.

** Remove an additional 1,800 lbs during a 24-hour period.

*** If the actual solids under aeration are less than the desired solids, reduce your current wasting rate.

4. Operation by or calculations of the F/M should not be on the basis of daily tests because flows and organic concentrations can vary widely on a day-to-day basis. One way to handle these variations is to calculate the F/M based on a seven-day *MOVING AVERAGE*[9] of food (COD, BOD, or TOC), flow and microorganisms (MLSS).

The range of organic loadings of activated sludge plants is described by the F/M. Different ranges of organic loadings are necessary for conventional, extended aeration, and high rate types of activated sludge systems. These ranges have been shown to produce activated sludge that settles well.

Table 2.5 presents the ranges of F/M that have been used successfully with the three loading conditions. The F/M values shown are expressed in terms of BOD, COD, and Total Organic Carbon (TOC). The TOC is an additional means of estimating organic loading. The values indicated are guidelines for process control, and they should not be thought of as minimums or maximums.

TABLE 2.5 TYPICAL RANGES FOR F/M LOADINGS

	Conventional AS Range F/M	Extended Aeration F/M	High-Rate Range F/M
BOD	0.1 to 0.5	0.05 to 0.1	0.5 to 2.5
COD(1)	0.06 to 0.3	0.03 to 0.06	0.3 to 1.5
TOC(2)	0.25 to 1.5	0.1 to 0.25	1.5 to 6.0

(1) Assumes BOD/COD for settled wastewaters = 0.6
(2) Assumes BOD/TOC for settled wastewaters = 2.5

The F/M is calculated from the amount of COD or BOD applied each day and from the solids inventory in the aeration tank.

EXAMPLE

Determine the food to microorganism (F/M) ratio for an activated sludge plant with a COD of 100 mg/*L* applied to the aeration tank, an influent flow of 7.5 MGD (28,390 cu m/day) and 33,075 lbs (15,000 kg) of solids under aeration. Seventy percent of the MLSS are volatile matter. All knowns are seven-day moving averages.

Known		Unknown
Infl. Flow, MGD	= 7.5 MGD	F/M, lbs COD/day/lb MLVSS
COD, mg/*L*	= 100 mg/*L*	
Solids under aeration, lbs	= 33,075 lbs	
MLSS VM, %	= 70%	

1. Calculate the food to microorganism ratio.

$$\text{F/M}, \frac{\text{1 lb COD/day}}{\text{lb MLVSS Solids}} = \frac{\text{Flow, MGD} \times \text{COD, mg}/L \times \text{8.34 lbs/gal}}{\text{Solids under aeration, lbs} \times \text{VM portion}}$$

$$= \frac{\text{7.5 MGD} \times \text{100 mg}/L \times \text{8.34 lbs/gal}}{\text{33,075 lbs} \times 0.70}$$

$$= \frac{\text{6,255 lbs COD/day}}{\text{23,150 lbs MLVSS}}$$

$$= \text{0.27 lbs COD/day/lb MLVSS}$$

The determination of WAS flow rates using F/M control technique is calculated in the same manner as for the sludge age technique. However, the solids inventory for the aeration tank can be more logically determined based on the COD or BOD concentration of the wastewater to be treated when using the F/M for process control. This procedure is shown in the following calculations.

EXAMPLE

Determine the desired waste activated sludge (WAS) flow rate using the F/M control technique. The influent flow is 7.5 MGD (28,390 cu m/day), total aeration tank volume is 1.2 MG (4,542 cu m), COD to aeration tank is 100 mg/*L*, the mixed liquor suspended solids (MLSS) are 3,300 mg/*L* and 70 percent volatile matter, the RAS suspended solids are 6,300 mg/*L* and the desired food to microorganism (F/M) ratio is 0.29. Current WAS flow rate is 0.085 MGD.

Known		Unknown
Infl. Flow, MGD	= 7.5 MGD	WAS Flow, MGD
Tank Vol., MG	= 1.2 MG	
COD, mg/*L*	= 100 mg/*L*	
MLSS, mg/*L*	= 3,300 mg/*L*	
MLSS VM, %	= 70%	
RAS Susp. Sol., mg/*L*	= 6,300 mg/*L*	
Desired F/M, $\frac{\text{lbs COD/day}}{\text{lb MLVSS}}$	$= 0.29 \frac{\text{lbs COD/day}}{\text{lb MLVSS}}$	
Current WAS, MGD	= 0.085 MGD	

1. Determine COD applied in pounds per day.

$$\text{COD, lbs/day} = \text{Flow, MGD} \times \text{COD, mg}/L \times \text{8.34 lbs/gal}$$

$$= \text{7.5 MGD} \times \text{100 mg}/L \times \text{8.34 lbs/gal}$$

$$= \text{6,255 lbs COD/day}$$

2. Determine the desired pounds of MLVSS.

$$\text{Desired MLVSS, lbs} = \frac{\text{COD applied, lbs/day}}{\text{F/M, lbs COD/day/lb MLVSS}}$$

$$= \frac{\text{6,255 lbs COD/day}}{\text{0.29 lbs COD/day/lb MLVSS}}$$

$$= \text{21,569 lbs MLVSS}$$

3. Determine the desired pounds MLSS.

$$\text{Desired MLSS, lbs} = \frac{\text{Desired MLVSS, lbs}}{\text{MLSS VM portion}}$$

$$= \frac{\text{21,569 lbs}}{0.70}$$

$$= \text{30,813 lbs}$$

4. Determine actual MLSS pounds under aeration.

$$\text{Actual MLSS, lbs} = \text{Tank Vol., MG} \times \text{MLSS, mg}/L \times \text{8.34 lbs/gal}$$

$$= \text{1.2 MG} \times \text{3,300 mg}/L \times \text{8.34 lbs/gal}$$

$$= \text{33,026 lbs}$$

---

[9] *Moving Average. To calculate the moving average for the food for the last 7 days, add up the COD values for the last 7 days and divide by 7. Each day add the most recent day to the sum of values and subtract the oldest value. By using the 7-day moving average, each day of the week is always represented in the calculations.*

5. Calculate the additional WAS flow, MGD, to maintain the desired food to microorganism (F/M) ratio.

$$\text{Additional WAS Flow, MGD} = \frac{\text{Solids Aerated, lbs - Desired Solids, lbs}}{\text{RAS Susp. Sol., mg}/L \times 8.34\text{ lbs/gal}}$$

$$= \frac{33{,}026\text{ lbs} - 30{,}813\text{ lbs}}{6{,}300\text{ mg}/L^{*} \times 8.34\text{ lbs/gal}}$$

$$= \frac{2{,}213\text{ lbs removed per day}^{**}}{52{,}542}$$

$$= 0.042\text{ MGD}^{***} \times 694\text{ GPM/MGD}$$

$$= 29\text{ GPM}$$

* Remember that mg/*L* is the same as lbs/M lbs.
** Remove 2,213 lbs during a 24-hour period.
*** If the actual solids under aeration are less than the desired solids, reduce or stop your current wasting rate.

6. Calculate the total WAS flow in MGD and GPM.

$$\text{Total WAS Flow, MGD} = \text{Current WAS Flow, MGD} + \text{Additional WAS Flow, MGD}$$

$$= 0.085\text{ MGD} + 0.042\text{ MGD}$$

$$= 0.127\text{ MGD} \times 694\text{ GPM/MGD}$$

$$= 88\text{ GPM}$$

The F/M control technique for sludge wasting is best used in conjunction with the MCRT control technique. Control to a desired MCRT is achieved by wasting an amount of the aeration tank solids inventory which in turn fixes or provides an F/M ratio.

2.312 MCRT Control

By using the MCRT, the operator can control the organic loading (F/M). In addition, the operator can calculate the amount of activated sludge that should be wasted in a logical manner.

Basically, the MCRT expresses the average time that a microorganism will spend in the activated sludge process. The MCRT value should be selected to provide the best effluent quality. This value should correspond to the F/M loading for which the process is designed. For example, a process designed to operate at conventional F/M loading rates may not produce a high quality effluent if it is operating at a low MCRT because the F/M may be too high for its design. Therefore you must find the best MCRT for your process by relating it to the F/M as well as the effluent COD, BOD, and suspended solids concentrations.

The MCRT also determines the type of microorganisms that predominate in the activated sludge because it has a direct influence on the degree of nitrification which may occur in the process. A plant operated at a longer MCRT of 15 to 20 days will generally produce a nitrified effluent. A plant operating with an MCRT of 5 to 10 days may not produce a nitrified effluent unless wastewater temperatures are unusually high (above 77°F or 25°C). Table 2.6 presents the typical range of MCRT values that will enable nitrification at various wastewater temperatures. MCRTs below the values listed in Table 2.6 are also possible under more optimum conditions, similarly, under less favorable conditions a higher MCRT may be required. The determination of a correct MCRT is only the first of many considerations found in operating an activated sludge plant to achieve nitrification. Nevertheless, the values shown have been used successfully to produce nitrified effluents at numerous plants where ammonia removal is required from the effluent, but not total nitrogen removal.

TABLE 2.6 MCRT NEEDED TO PRODUCE A NITRIFIED EFFLUENT AS RELATED TO THE TEMPERATURE

Temperature, °C	MCRT, Days
10	30
15	20
20	15
25	10
30	7

As stated earlier, MCRT expresses the average time that a microorganism spends in the activated sludge process. The MCRT and the WAS flow rate for maintaining a desired MCRT are shown in the following example.

EXAMPLE

Determine the waste activated sludge (WAS) flow rate using the MCRT technique. The influent flow is 7.5 MGD (28,390 cu m/day), total aeration tank volume is 1.2 MG (4,542 cu m), mixed liquor suspended solids (MLSS) are 3,300 mg/*L*, RAS suspended solids are 6,300 mg/*L*, effluent suspended solids are 15 mg/*L*, and the desired mean cell residence time (MCRT) is 8 days.

Known		Unknown
Infl. Flow, MGD	= 7.5 MGD	WAS Flow, MGD
Tank Vol., MG	= 1.2 MG	
MLSS, mg/*L*	= 3,300 mg/*L*	
RAS SS, mg/*L*	= 6,300 mg/*L*	
Effl. SS, mg/*L*	= 15 mg/*L*	
Desired MCRT, days	= 8 days	

$$\text{MCRT,}^{*}\text{ days} = \frac{\text{Suspended Solids in Aerator, lbs}}{\text{Susp. Sol. Wasted, lbs/day} + \text{Susp. Sol. in Effl., lbs/day}}$$

1. Determine suspended solids in aerator in pounds.

$$\text{SS in Aerator, lbs} = (\text{Aerator, MG}) \times \text{MLSS, mg}/L \times 8.34\text{ lbs/gal}$$

$$= 1.2\text{ MG} \times 3{,}300\text{ mg}/L \times 8.34\text{ lbs/gal}$$

$$= 33{,}026\text{ lbs}$$

2. Determine suspended solids lost in effluent in pounds per day.

$$\text{SS lost in effl., lbs/day} = \text{Infl. Flow, MGD} \times \text{Effl. SS, mg}/L \times 8.34\text{ lbs/gal}$$

$$= 7.5\text{ MGD} \times 15\text{ mg}/L \times 8.34\text{ lbs/day}$$

$$= 938\text{ lbs/day}$$

3. Determine the desired suspended solids wasted in pounds per day.

$$\text{MCRT, days} = \frac{\text{SS in Aerator, lbs}}{\text{SS wasted, lbs/day} + \text{SS in Effl., lbs/day}}$$

$$\text{SS Wasted, lbs/day} = \frac{\text{SS in Aerator, lbs}}{\text{MCRT, days}} - \text{SS in Effl., lbs/day}$$

$$= \frac{33{,}026\text{ lbs}}{8\text{ days}} - 938\text{ lbs/day}$$

$$= 4{,}128\text{ lbs/day} - 938\text{ lbs/day}$$

$$= 3{,}190\text{ lbs/day}$$

**NOTE:* Some operators use volatile suspended solids instead of suspended solids.

MCRT may be calculated three different ways:

1. SS in Aerator, lbs,
2. SS in Aerators and Secondary Clarifiers, lbs, and
3. SS in Aerators and Secondary Sludge Blankets, lbs.

4. Determine the waste activated sludge (WAS) flow rate, MGD.

$$\text{SS Wasted, lbs/day} = \text{WAS Flow, MGD} \times \text{RAS SS, mg/}L \times 8.34 \text{ lbs/gal}$$

$$\begin{aligned}\text{WAS Flow, MGD} &= \frac{\text{SS Wasted, lbs/day}}{\text{RAS SS, mg/}L \times 8.34 \text{ lbs/gal}}\\ &= \frac{3{,}190 \text{ lbs/day}}{6{,}300 \text{ mg/}L \times 8.34 \text{ lbs/gal}}\\ &= 0.06 \text{ MGD} \times 694 \text{ GPM/MGD}\\ &= 42 \text{ GPM}\end{aligned}$$

This means that for the next 8 days, approximately 60,000 gallons per day should be wasted from the RAS system. However, the WAS flow rate should be determined and adjusted daily to maintain the desired MCRT.

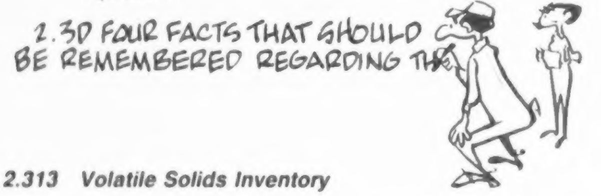
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

2.3D What four facts should be remembered regarding the F/M method of control?

2.3E Calculate the desired pounds of MLSS if the desired F/M ratio is 0.30 lbs COD/day/lb MLVSS if 7,000 lbs of COD per day are added and the volatile matter is 70 percent of the MLSS.

2.3F What does the Mean Cell Residence Time (MCRT) represent?


2.3D FOUR FACTS THAT SHOULD BE REMEMBERED REGARDING THE

2.313 Volatile Solids Inventory

If wasting is done from the RAS, the operator must measure the volatile suspended matter in the RAS to obtain average concentrations. If the volatile content in the RAS suspended solids concentration is decreasing, the WAS flow rate must be increased proportionally to waste the proper amount of volatile suspended solids. Similarly, if there is an increase in the RAS volatile content, the WAS flow rate must be decreased proportionally to avoid losing or wasting too many microorganisms. Using volatile suspended solids values to control the WAS flow will take care of this problem.

When continuous wasting is practiced, the operator should check the RAS volatile suspended solids at least once every shift and make the appropriate WAS flow adjustment.

EXAMPLE

An activated sludge plant is currently wasting 0.05 MGD (35 GPM or 2.18 *L*/sec). The return activated sludge (RAS) volatile suspended solids (VSS) on day 1 are 6,000 mg/*L* and on day 2 (the next day) the RAS VSS are 7,500 mg/*L*. Determine the adjusted waste activated sludge (WAS) rate based on the increase in return activated sludge (RAS) volatile suspended solids (VSS) from 6,000 to 7,500 mg/*L*.

Known		**Unknown**
WAS Flow, MGD	= 0.05 MGD	Adjusted WAS Flow, MGD
RAS VSS, mg/*L* (day 1)	= 6,000 mg/*L*	
RAS VSS, mg/*L* (day 2)	= 7,500 mg/*L*	

1. Calculate the adjusted waste activated sludge (WAS) flow in MGD and GPM.

$$\begin{aligned}\text{Adj. WAS Flow, MGD} &= \frac{\text{RAS VSS for day 1, mg/}L \times \text{WAS Flow, MGD}}{\text{RAS VSS for day 2, mg/}L}\\ &= \frac{6{,}000 \text{ mg/}L \times 0.05 \text{ MGD}}{7{,}500 \text{ mg/}L}\\ &= 0.04 \text{ MGD} \times 694 \text{ GPM/MGD}\\ &= 28 \text{ GPM}\end{aligned}$$

When intermittent wasting is practiced, the operator must check the RAS volatile suspended solids to calculate the necessary WAS flow. In addition, this calculation must be readjusted for the reduced time of wasting.

EXAMPLE

In the previous example, the waste activated sludge pumping (WAS) period is 4 hours per day and the calculated WAS flow was 0.04 MGD or 28 GPM (1.75 *L*/sec). Calculate the WAS flow.

Known		**Unknown**
WAS Flow, MGD	= 0.04 MGD	WAS Flow, MGD for 4 hour/day wasting period
Wasting Time, hr/day	= 4 hrs/day	

1. Determine the WAS flow for a 4 hour-day wasting period.

$$\begin{aligned}\text{New WAS flow, MGD} &= \frac{\text{WAS Flow, MGD} \times 24 \text{ hr/day}}{4 \text{ hours of wasting/day}}\\ &= 0.04 \text{ MGD} \times \frac{24 \text{ hr/day}}{4 \text{ hr/day}}\\ &= 0.24 \text{ MGD} \times 694 \text{ GPM/MGD}\\ &= 167 \text{ GPM}\end{aligned}$$

The operator would repeat the WAS flow calculation for each wasting period to take into account the RAS volatile suspended solids variations.

Intermittent wasting of sludge has the advantage that less variation in the suspended matter concentration will occur during the wasting period, and the amount of sludge wasted will be more accurately known. The disadvantages of intermittent wasting are that the sludge handling facilities in the treatment plant may be loaded at a higher hydraulic loading rate and that the activated sludge process is out of balance for a period of time until the microorganisms regrow to replace those wasted over the shorter period of time. Intermittent wasting usually is not practiced in plants treating more than 10 MGD (37,800 cu m/day).

In using either of these methods for wasting, the operator does not have complete control of the amount of activated sludge wasted due to the solids lost in the effluent. This "wasting" of activated sludge in the effluent must be accounted for with any method of process control or the system will always be slightly out of balance. The loss of activated sludge in the effluent generally accounts for less than five percent of the total solids that need to be wasted; however, it is necessary to be aware of this loss and to be able to take it into account by the methods shown in Section 2.312, "MCRT Control." The need for taking into account the solids lost in the effluent is especially important if one encounters situations where large concentrations of suspended solids are washed out in the secondary effluent, as in the case of sludge bulking.

Proper control of the WAS will produce a high quality effluent with mininum operational difficulties.

2.314 MLVSS Control

This technique for process control is used by many operators because it is simple to understand and involves a minimum amount of laboratory control. The MLVSS control technique usually produces good quality effluent as long as the incoming wastewater characteristics are fairly constant with minimal variations in influent flow rates.

With this technique, the operator tries to maintain a constant MLVSS concentration in the aeration tank to treat the incoming wastewater organic load. To put it in simple terms, if it is found that a MLVSS concentration of 2,000 mg/*L* produces a good quality effluent, the operator must waste sludge from the process to maintain that concentration. More sludge is wasted until the desired level is reached again.

The laboratory control tests and operational data involved in using this technique include the following:

1. MLVSS Concentration
2. RAS Volatile Suspended Solids Concentration
3. Influent Wastewater Flow Rate
4. Volume of Aeration Tank

Whether a new plant is being started or the operation of an existing plant is being checked, this control technique is used to indicate when activated sludge should be wasted. In most cases it is not the most reliable technique because it ignores process variables such as F/M and microorganism growth rate necessary for maintaining optimum system balance. When operational problems occur, the operator is unable to make rational process adjustments due to the lack of process control data.

The control technique is implemented by choosing an MLVSS concentration which produces the highest quality effluent while maintaining a stable and economical operation. WAS flow rates are determined as follows:

EXAMPLE

A 1.2 MG (4,542 cu m) aeration tank has a mixed liquor suspended solids (MLSS) concentration of 3,300 mg/*L*. The return activated sludge (RAS) suspended solids concentration is 6,300 mg/*L*. The volatile portion of both suspended solids is 70 percent. Experience has shown that the desired mixed liquor volatile suspended solids (MLVSS) in the aeration tank is approximately 21,250 pounds (9,639 kg). Determine the desired waste activated sludge (WAS) flow rate if the current WAS flow rate is 0.15 MGD.

Known		Unknown
Tank Vol., MG	= 1.2 MG	Desired WAS Flow, MGD
MLSS, mg/*L*	= 3,300 mg/*L*	
RAS SS, mg/*L*	= 6,300 mg/*L*	
Volatile Portion	= 0.70	
Desired MLVSS, lbs	= 21,250 lbs	
Current WAS Flow, MGD	= 0.15 MGD	

1. Determine mixed liquor volatile suspended solids (MLVSS) under aeration in pounds.

$$\begin{aligned}\text{Actual MLVSS, lbs} &= \text{Tank Vol., MG} \times \text{MLSS, mg}/L \times \text{Volatile} \times 8.34\ \text{lbs/gal}\\ &= 1.2\ \text{MG} \times 3{,}300\ \text{mg}/L \times 0.70 \times 8.34\ \text{lbs/gal}\\ &= 23{,}120\ \text{lbs}\end{aligned}$$

2. Determine the pounds of volatile solids to be wasted.

$$\begin{aligned}\text{Amt. Wasted, lbs} &= \text{Actual MLVSS, lbs} - \text{Desired MLVSS, lbs}\\ &= 23{,}120\ \text{lbs} - 21{,}250\ \text{lbs}\\ &= 1{,}870\ \text{lbs to be wasted per day}\end{aligned}$$

3. Determine the additional waste activated sludge (WAS) flow rate in MGD and GPM.

$$\text{Amt. Wasted, lbs/day} = \text{WAS Flow, MGD} \times \text{RAS SS, mg}/L \times \text{Vol.} \times 8.34\ \text{lbs/gal}$$

or

$$\begin{aligned}\text{WAS Flow, MGD} &= \frac{\text{Amount Wasted, lbs/day}}{\text{RAS SS, mg}/L \times \text{Volatile} \times 8.34\ \text{lbs/gal}}\\ &= \frac{1{,}870\ \text{lbs/day}}{6{,}300\ \text{mg}/L \times 0.70 \times 8.34\ \text{lbs/gal}}\\ &= 0.05\ \text{MGD} \times 694\ \text{GPM/MGD}\\ &= 35\ \text{GPM}\end{aligned}$$

4. Determine the desired WAS flow rate in MGD and GPM.

$$\begin{aligned}\text{Desired WAS Flow, MGD} &= \text{Current WAS Flow, MGD} + \text{Additional WAS Flow, MGD}\\ &= 0.15\ \text{MGD} + 0.05\ \text{MGD}\\ &= 0.20\ \text{MGD} \times 694\ \text{GPM/MGD}\\ &= 140\ \text{GPM}\end{aligned}$$

2.32 Microscopic Examination

Some operators use a microscope to examine the microorganisms in the mixed liquor for an indication of the condition of the activated sludge treatment process. The majority of the BOD is removed by common zoogleal microorganisms. The microorganisms that are important indicators in the activated sludge process are the *PROTOZOA*[10] and *ROTIFERS*[11]. The protozoa eat the bacteria and help produce a clear effluent. The presence of rotifers is an indication of a stable effluent. If excessive *FILAMENTOUS BACTERIA*[12] are observed, you usually can expect an activated sludge that settles poorly.

If most of the microorganisms in the mixed liquor suspended solids are protozoa (ciliates) and rotifers, you can expect a good settling activated sludge. By using the proper return activated sludge (RAS), waste activated sludge (WAS), and aeration rates, you can produce an effluent with a BOD of less than 10 mg/*L*.

Apparently some filamentous bacteria are good, but too many are bad. Filamentous bacteria can form a network or backbone upon which activated sludge floc can gather and form an excellent settling floc. If the filaments become excessive, a bridging mechanism forms which prevents the activated sludge from flocking or gathering together. If the floc cannot come in contact with each other, sufficient particle mass will not be produced to achieve a good settling floc.

---

[10] *Protozoa (pro-toe-ZOE-ah). A group of microscopic animals (usually single-celled) that sometimes cluster into colonies.*

[11] *Rotifers (ROE-ti-fers). Microscopic animals characterized by short hairs on their front end.*

[12] *Filamentous Bacteria (FILL-a-MEN-tus). Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomycetes.*

Three groups of protozoa are important to the operator of an activated sludge process.

1. Amoeboids
2. Flagellates
3. Ciliates

AMOEBOIDS (Fig. 2.8)

Look for amoeboids in the mixed liquor suspended solids floc during start-up periods or when the process is recovering from an upset condition.

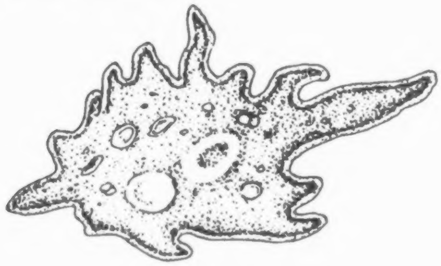


Fig. 2.8 Amoeboids

FLAGELLATES (Fig. 2.9)

Flagellates are usually found with a light, dispersed, straggler floc, a low population of microorganisms, and a high organic (BOD) load. With a high organic (BOD) load, other microorganisms will start to thrive, a more dense sludge floc will develop, and the flagellate population will decrease.

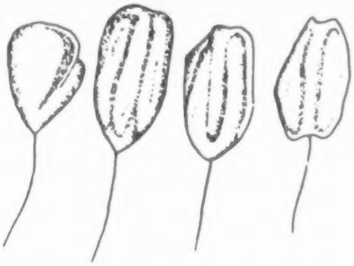


Fig. 2.9 Flagellates

CILIATES

Ciliates are usually found in large numbers when the activated sludge is in a fair to good settling condition. Ciliates are classified into two basic groups, free swimming ciliates (Fig. 2.10) and stalked ciliates (Fig. 2.11).

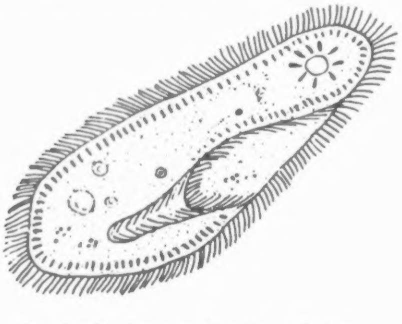


Fig. 2.10 Free swimming ciliates

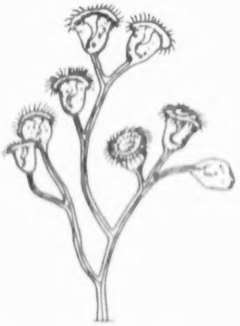


Fig. 2.11 Stalked ciliates

Free swimming ciliates are usually present when there is a large number of bacteria in the activated sludge. These organisms feed on bacteria and help produce a clear effluent. They are associated with a good degree of treatment.

Stalked ciliates are usually present when the free swimming ciliates are unable to compete for the available food. A large number of stalked ciliates and rotifers (Fig. 2.12) will indicate a stable and efficiently operating activated sludge process.

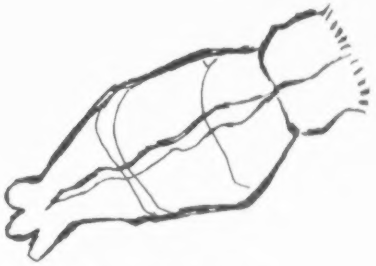


Fig. 2.12 Rotifers

The types of microorganisms and the numbers of microorganisms can be used as a guide in making activated sludge process control adjustments. Figure 2.13 can help you determine whether the mean cell residence time (MCRT) should be increased or decreased. A decline in microorganisms, especially ciliates, is frequently a warning of a poorly settling sludge. If a relatively large number of amoeboids and flagellates are observed, try increasing the MCRT. If the numbers of microorganisms are relatively low with rotifers predominating and you have a pin floc, try decreasing the MCRT.

These observations can allow an operator to detect a change in organic loading or in level of a toxic chemical before the activated sludge process becomes upset. The changes in type and number of microorganisms should be compared with observations of the settling characteristics of the mixed liquor suspended solids in the 30-minute settleability test and with the calculated food to microorganism ratio.

In summary, large numbers of ciliates and rotifers are an indication of a stable activated sludge process that will produce a high quality effluent.

Major portions of this section were taken from *PROCESS CONTROL MANUAL FOR AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES*, Municipal Operations Branch, Office of Water Program Operations, U. S. Environmental Protection Agency, Washington, D. C. 20460.

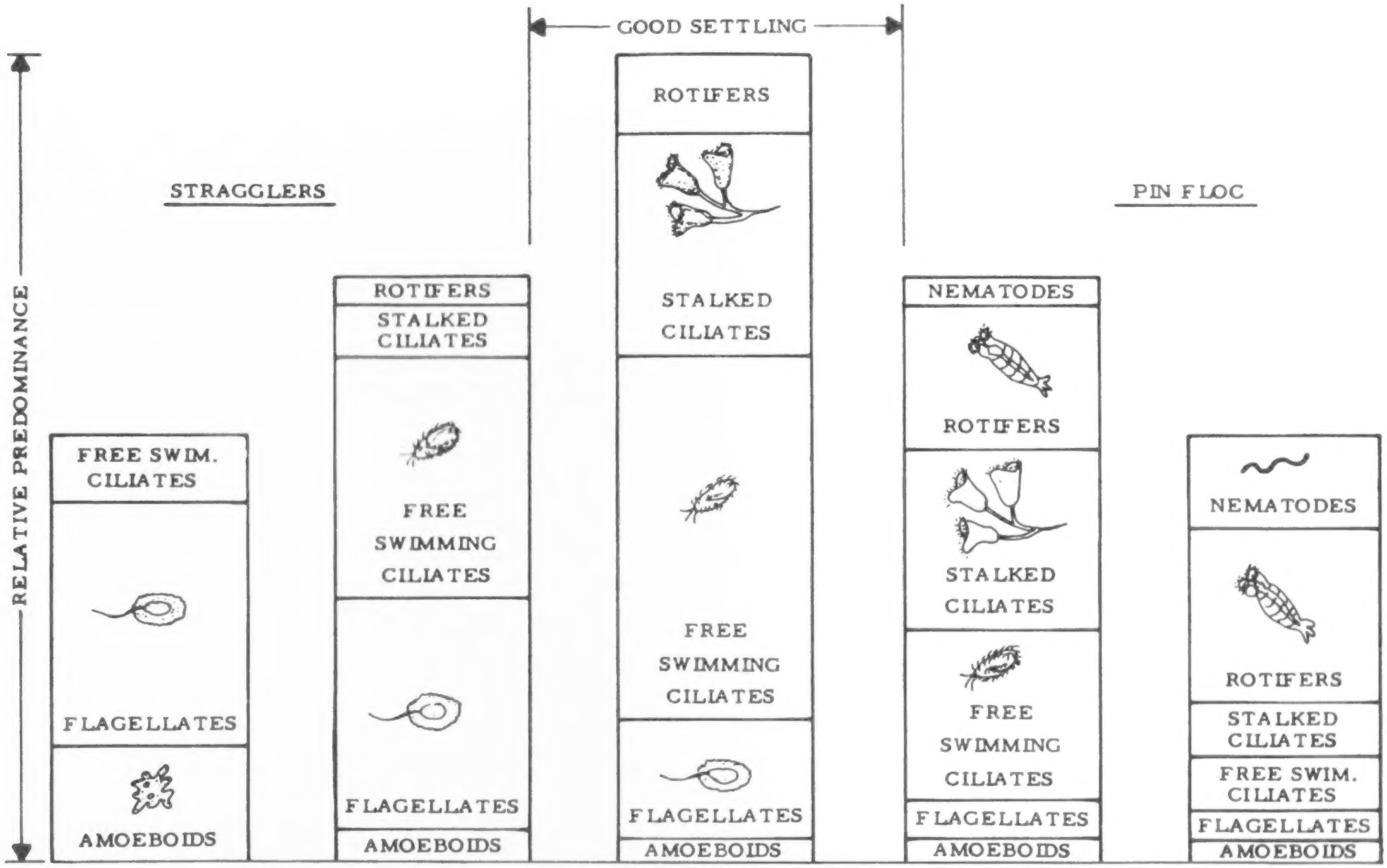


Fig. 2.13 Relative number of microorganisms vs. sludge quality

2.33 The Al West Method

Section 2.2, "Return Activated Sludge" and 2.3, "Waste Activated Sludge" have outlined various methods operators used to "control" their activated sludge process. Mr. West has correctly observed that the activated sludge "process is *NOT* controlled by attempting to achieve *PRECONCEIVED* levels of *INDIVIDUAL* variables such as mixed liquor sludge concentration, mean cell residence time and food to microorganism ratios. *CONTROL* tests such as final clarifier sludge blanket depth determinations, mixed liquor and return sludge concentrations (by centrifuge) and sludge settleability are used to define sludge quality and process status and to determine process adjustments." Mr. West worked continuously to develop better ways for operators to control the activated sludge process.

2.34 Summary on RAS and WAS Rates

How should you operate your activated sludge process? Only you can answer this question. In Chapters 8 and 11 of Volumes I and II of *OPERATION OF WASTEWATER TREATMENT PLANTS*, we outlined what we consider are simple and direct procedures for operating package plants, oxidation ditches and conventional activated sludge plants. In Chapter 2 of this manual, various alternative methods were outlined on how to control the activated sludge process.

What counts is the effluent quality from your activated sludge plant. The effluent quality is influenced by influent characteristics and conditions in the aeration tank and secondary clarifier. Observe these characteristics and conditions; you must be alert for any change and make appropriate adjustments to control the activated sludge process. *EVERY OPERATOR ON EVERY SHIFT MUST FOLLOW THE SAME PROCEDURES. TRY NOT TO ADJUST YOUR RAS AND WAS RATES BY MORE THAN 10 OR 15 PERCENT FROM ONE DAY TO THE NEXT DAY. SELECT A METHOD YOU UNDERSTAND, RECORD AND ANALYZE DATA, STICK WITH YOUR METHOD AND YOU CAN MAKE IT WORK TO PRODUCE A GOOD EFFLUENT.*

2.35 Acknowledgment

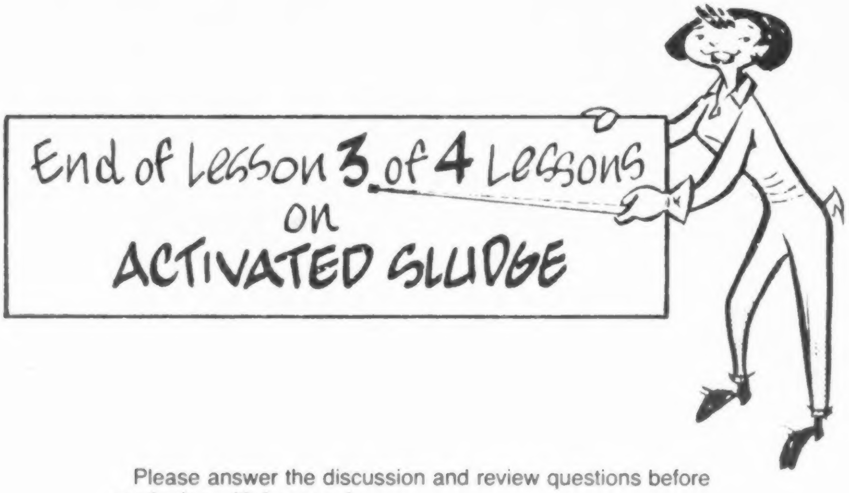
Major portions of Section 2.3 were adapted from *PROCESS CONTROL MANUAL FOR AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES*, Municipal Operations Branch, Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C. 20460.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

2.3G Which microorganisms are important indicators in the activated sludge process?

2.3H In the Al West method, what important activated sludge control tests are used to define sludge quality and process status?


End of Lesson 3 of 4 Lessons
on
ACTIVATED SLUDGE

Please answer the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 3 of 4 Lessons)

Chapter 2. ACTIVATED SLUDGE

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 2.

9. What items are affected by the amount of waste activated sludge (WAS) removed from the process?
10. How will you know when you have established the best mode of process control for your plant?
11. What is the basis for the F/M method of controlling the activated sludge process?
12. How would you adjust the MCRT to produce a nitrified effluent?
13. What are the advantages and limitations of intermittent wasting of activated sludge?
14. How would you select the RAS and WAS rates for your activated sludge plant?

CHAPTER 2. ACTIVATED SLUDGE

(Lesson 4 of 4 Lessons)

2.4 TREATMENT OF BOTH MUNICIPAL AND INDUSTRIAL WASTES

2.40 Monitoring Industrial Waste Discharges (Also see Chapter 5, "Monitoring Industrial Waste," in *INDUSTRIAL WASTE TREATMENT*.)

Industrial manufacturing processes of most types generate some waste materials. These waste materials take the form of liquid, gaseous or solid residuals. In most cases, the deliberate and indiscriminate disposal of these waste materials to the collection system will have a deteriorating effect upon the activated sludge process and possible detrimental effects on the treatment plant effluent receiving waters.

As discussed in Chapter 11, Section 11.011, you should become acquainted with the various industrial facilities in your area to determine what, if any, adverse impact they may create on your activated sludge process.

2.400 Establishing a Monitoring System

Regulations at both state and federal levels usually require that industrial waste monitoring be established as an important part of an industrial waste control and treatment system.

An industrial waste monitoring program is valuable for the following reasons:

1. To assure regulatory agencies of industrial compliance with discharge requirements and implementation schedules set forth in the discharge permit,
2. To maintain sufficient control of treatment plant operations to prevent NPDES permit violations, and
3. To gather necessary data for the future design and operation of the treatment plant.

In establishing a monitoring program, one of the first tasks should be an examination of the wastewater characteristics of each industry that discharges to the collection system. Awareness of the specific types of harmful waste materials that may enter the collection system will help you prepare a monitoring program to protect the treatment plant and receiving waters.

Some industries pretreat wastewaters before discharge to the collection system to recover valuable materials, to reduce sewer-service charges, and to keep undesirable constituents out of the sewers and treatment plant. However, if undesirable constituents are known to be present in the municipal wastewater stream, pretreatment of the industrial wastewater portion must be enforced to reduce the constituents to acceptable levels. Proper monitoring at the site of an industrial wastewater pretreatment plant is essential. Additionally, if it is likely that an accidental spill or unlawful discharge may escape pretreatment and enter the collection system, a sophisticated monitoring system should be installed at your treatment plant. The reasons for wastewater monitoring at the treatment plant itself include establishing a last point of measurement of certain problem constituents before entering the unit processes so that the operator can start corrective operational measures where possible.

2.401 Automatic Monitoring Units

Automatic monitoring of several wastewater characteristics has been a dependable method of alerting the operator to abnormal influent wastewater conditions. Numerous water quality indicators are used for operational controls, yet the number of water quality indicators that can be automatically measured without difficulty is limited. Therefore, it is essential that the operator also rely on the appearance and odor of the influent wastewater as part of the monitoring program at the treatment plant.

Some of the more common monitoring devices include:

1. Flow measuring,
2. pH monitoring,
3. Oxidation potential monitoring (conductivity),
4. Suspended solids monitoring,
5. DO monitoring,
6. Wastewater samplers, and
7. Gas-phase hydrocarbon analyzer.

Normally, data is recorded on a strip chart recorder; however, other equipment, such as pumps or valves may be activated by these monitoring devices. The monitoring systems should also be combined with an alarm system that will give the operator warning when a high concentration of an undesirable water quality indicator reaches the monitoring station.

2.41 Common Industrial Wastes

Reduction and/or elimination of harmful waste constituents from industrial discharges may be controlled by enforcing your municipal sewer ordinance. Several objectionable industrial waste constituents and the possible effects of each waste are discussed below.

1. Flammable Oils. Examples of flammable oils are crude gasoline, benzene, naphtha, fuel oil, and mineral oil. These substances are not soluble and tend to collect in pools, thus creating potential explosive conditions. When methane gas is mixed with flammable oils, a very powerful explosion may result.
2. Toxic Gases. Toxic gases such as hydrogen sulfide (H_2S), methane (CH_4), and hydrogen cyanide (HCN) are often present or may be formed in industrial discharges. Wastewater with high quantities of sulfate can cause problems in anaerobic decomposition, due to the formation of H_2S. Also, cyanide combines with acid wastes to form the extremely toxic gas, HCN.
3. Oils and Greases. A municipal plant generally does not have facilities for the removal of significant quantities of oils and grease. Pretreatment of wastewater may be desirable to reduce the total concentration of oils and grease (hexane extractables). In general, emulsified oils and greases of vegetable and animal origin are biodegradable and can be successfully treated by a properly designed municipal treatment facility. However, oils and greases of mineral origin may cause problems and these are the constituents generally requiring pretreatment.
4. Settleable Solids. Settleable solids cause obstructions in the sewer system by settling and accumulating. At places where wastewater accumulates, anaerobic decomposition may take place, producing undesirable products, such as hydrogen sulfide and methane.

   High settleable solids concentrations may overload the capacity of the treatment plant.
5. Acids or Alkalies. Acids or alkalies are both corrosive and may also interfere with biological treatment. Even neutral sulfate salts may cause corrosion, since the sulfate can be biologically reduced to sulfide and then oxidized to sulfuric acid.
6. Heavy Metals. Heavy metals may be toxic to biological treatment systems or to aquatic life in the receiving water and may adversely affect downstream potable water supplies.
7. Cyanides. Cyanides are toxic to bacteria and may cause hazardous gases in the sewer.
8. Organic Toxicants. Pesticides and other extremely toxic substances in wastewater are objectionable except in very small concentrations. Even if the biological treatment systems are not altered by higher concentrations, toxicants may still damage receiving surface water quality.

2.42 Effects of Industrial Wastes on the Treatment Plant Unit Processes

When undesirable industrial constituents enter the municipal waste stream, certain adverse effects on common unit treatment processes can be expected. For example, acids and corrosive materials would damage the conveyance system of pipes and pumps. Dangerous gases and explosive materials create hazards to plant personnel. Other constituents, such as heavy metals or toxic organics, may actually inhibit or kill the microorganisms at the treatment plant.

Some of the more common adverse effects that industrial waste constituents have on unit processes are listed below.

A. Sewer System
   1. Corrosion caused by acids
   2. Clogging due to fats and waxes
   3. Hydraulic overload by discharge of cooling waters
   4. Potential explosion danger with gasolines and other fuels

B. Grit Channels
   1. Overloading with high grit concentrations
   2. Increased organic content of grit
   3. Intermittent flow reduces removal efficiency

C. Screens and Comminutors
   1. Overload with excess solids
   2. Excessive wear on comminutor cutting surfaces by hard materials

D. Clarifiers
   1. Fluctuating hydraulic loadings reduce removal efficiencies
   2. Scum problems from excessive quantities of oils
   3. Impaired effluent quality caused by finely divided suspended solids
   4. Excessive sludge quantities with high suspended solids concentrations

E. Sludge Digesters
   1. Negative effects on sludge digestion caused by inorganic solids
   2. Overload caused by excessive solids
   3. Increased scum layers caused by excessive organic solids
   4. pH problems from an industrial wastewater with a high sugar content
   5. Toxicants

F. Activated Sludge
   1. Deterioration in quality with transient loading
   2. Excessive carbohydrate concentrations can cause bulking or poorly settling sludge
   3. Toxicants
   4. Foaming problems

2.43 Operational Strategy

2.430 Need for a Strategy

Adverse effects to the activated sludge process can be significantly reduced if the operator has a plan of operation or an operational strategy ready to implement when adverse industrial constituents enter the treatment plant.

This section will discuss the observations and corrective actions (operational strategy) taken at a typical activated sludge plant when (1) a toxic waste (cyanide), and (2) a high BOD waste (milk) enter the treatment plant mixed with the domestic wastewater.

This typical plant monitors the influent pH and the aeration tank DO. These are the only two water quality indicators that are monitored continuously. The operators at this plant rely heavily on sight and smell observations of the influent wastewater, aeration tank mixed liquor, and the secondary effluent as the first indicators of shock or overload conditions at the plant. These observations allow the proper corrective actions to be implemented before significant damage to the activated sludge process occurs.

Our typical treatment plant is designed to operate in the contact stabilization modification of the activated sludge process. This mode of operation is very desirable when industrial waste constituents that are harmful to the organisms in activated sludge may occur unexpectedly in the treatment plant influent. The advantage of operating in this mode is discussed in Chapter 11, Section 11.91.

The average operating data for our typical plant is as follows:

Peak influent flow	: 17.0 MGD
Raw wastewater COD	: 400 to 450 mg/*L*
Primary effluent feed to the aeration tanks	: Three-point step feed
Aeration contact basin F/M	: 0.5 to 0.8 lbs COD/day/lb MLVSS
DO through the system	: 0.05 to 5.0 mg/*L*
Sludge aeration time	: 7 to 12 hours to keep most of the biomass under aeration
Ammonia oxidation	: 30 to 50 percent
Secondary effluent nitrate	: 0.3 to 1.5 mg/*L*
Secondary effluent SS	: 5 to 10 mg/*L* (varies with the waste)
Air-to-flow ratio	: 1.8 to 2.5 cu ft/gal
RAS flow rate control	: Flow paced and allow "zero" sludge blanket in the secondary clarifier

2.431 Recognition of a Toxic Waste Load

In our sample plant, the first indication of a toxic waste load within the treatment plant is recognized by observing the aeration basin DO recording device. As the toxic load moves into and through the aeration basin, the DO residual will increase significantly. A DO increase without an air input increase indicates that the toxic waste load is killing the microorganisms in the aeration tank, thus reducing the oxygen uptake (respiration) by the microorganisms.

A second indication of a toxic waste reaching the plant may be observed in the secondary clarifier effluent. The effluent will begin to exhibit floc carry-over (an indication of cell death). The degree of carry-over will depend on the substance and quantity of the toxic waste.

When a toxic substance is known to have entered the treatment plant, the operator should make every effort to obtain a sample of the wastewater and have the sample analyzed as soon as possible to determine the toxic constituents. A record of these upset conditions and the constituents involved is very important so that if uncontrollable problems develop at the treatment plant, the records can be reviewed in an attempt to determine the input source.

2.432 Operational Strategy for Toxic Wastes

The operator's primary mission in the case of toxic wastes is to save the activated sludge system.

When the operator in our sample plant recognizes a toxic waste condition, the RAS flow is reduced significantly to keep as many of the bacteria affected by the toxic waste in the secondary clarifiers. The operator then significantly increases the WAS flow to purge the activated sludge process of the toxic waste and the sick or dead microorganisms. Additionally, every attempt is made to process the toxic waste flow through the plant as fast as possible to reduce contamination of other unit processes such as anaerobic or aerobic digesters.

The toxic waste processing time through our typical plant may vary from 30 minutes to 2 hours.

2.433 Recognition of a High Organic Waste Load

The first indication of a high organic waste load within the treatment plant is recognized by observing the aeration basin DO recording device. As the high organic load moves into and through the aeration basin, the DO residual will decrease significantly. A DO decrease without an air input decrease indicates that the high organic waste load is too great for the available microorganisms to properly assimilate and metabolize the waste (food to microorganism ratio is out of balance because of a greater BOD (food)).

If the high organic waste load is significant, the nutrient content of the municipal waste may be inadequate for proper biological activity. Therefore, nitrogen and phosphorus can be added on the basis of a total carbon measurement of the influent wastestream to ensure adequate amounts of these nutrients.

The quantity of nitrogen and phosphorus required for a waste can be estimated from the quantity of sludge produced per day. The pounds of nitrogen required per day will be about 10 percent of the volatile solids (dry weight) produced each day. The phosphorus requirement will be one-fifth of the nitrogen requirement. The amounts of nitrogen and phosphorus added daily are equal to the differences between the quantity required and the quantity in the wastes.

$$\text{Additional Nitrogen, lbs/day} = \text{Nitrogen Required, lbs/day} - \text{Nitrogen in Wastes, lbs/day}$$

A second indication of high organic waste reaching the plant may be observed in the secondary clarifier effluent. The effluent will become more turbid (less clear) indicating that the waste flow has not been adequately treated.

The sampling and analysis recommended in Section 21.401 should also be implemented in this situation.

2.434 Operational Strategy for High Organic Waste Loads

The operator's primary mission in the case of high organic loads is to improve the microorganism treatment efficiency.

Upon recognizing a high organic waste load condition, the RAS flow must be significantly increased to provide more microorganisms to the aeration contact basin to adequately treat the high organic waste. The rate of RAS increase must be accomplished gradually so that both design hydraulic and solids loading rates for the secondary clarifiers are not exceeded.

In addition, every attempt should be made to increase the air or oxygen input to maintain proper DO levels in the aeration basins. If appropriate, nitrogen and phosphorus should be added to provide the additional nutrients needed by the microorganisms.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

2.4A Why is an industrial waste monitoring program valuable for the operator of an activated sludge plant?

2.4B List five common wastewater monitoring devices.

2.4C What would you do if a high organic waste load entered your activated sludge plant?

2.5 INDUSTRIAL WASTE TREATMENT

2.50 Need to Treat Industrial Wastes

As the operator of an industrial wastewater treatment plant, it is your responsibility to ensure that required sewer-use standards or effluent quality standards are achieved in order that the production system may remain on-line. Because of tighter restrictions on the quality of industrial wastewater that can be discharged to municipal sewer systems or receiving streams, your industrial facility may be required to pretreat the industrial process wastewaters. This pretreatment can be costly, but failure to properly pretreat these wastewaters may result in excessive sewer use fees and treatment charges, in severe fines for violations and possible production shutdowns. Many industries are finding it more economical to build, operate and maintain their own treatment facilities than to pay for pretreatment and use of municipal treatment plants.

This section will provide you with information necessary to increase your process awareness and alert you to precautions required in operating your activated sludge industrial wastewater treatment plant.

Although there is a wide variety of applications of the activated sludge process to industrial wastewater treatment in operation today, this section will concentrate on some typical plants which treat wastes from fruit and vegetable processing, paper product manufacturing, and petroleum refining.

2.51 Characterization of Influent Wastes

The character of the wastewater is dependent on the particular production process and the way it is operated. The first step to successful operation of your treatment plant is to characterize the wastewaters through various analyses. These characteristics describe the concentrations or amounts of wastes in the wastewaters and include BOD, total suspended solids, settleable solids, COD, pH, DO, temperature, total solids, dissolved solids, chloride, nitrogen, and phosphorus. These pollutants are often used to determine the fees paid by industry for use of municipal collection systems and treatment plants. Other pollutants that are measured included toxic substances such as arsenic, zinc and copper. Toxic substances usually must be pretreated by industry. The procedures for measuring the concentrations or amounts of these wastes are outlined in Chapter 16, "Laboratory Procedures and Chemistry," Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS.*

Another important characteristic of the wastewater being treated is the flow. Flow rate should be described in terms of the daily average and also the fluctuations. Because many industrial facilities do not generate consistent waste flows and constituents over a 24-hour day or 7-day week, you must determine when the variations can be expected and operate your activated sludge process in a manner that anticipates these variables and does not allow these fluctuations to cause a deterioration of the quality of the plant effluent. Effective sewer-use ordinances require that industry notify the operator of a municipal treatment plant whenever a significant accidental discharge (spill or dump) or process failure might upset a treatment plant. By warning the operator of the volume and nature of the discharge, provisions can be made to handle the waste when it reaches the plant. Process supervisors should notify the operators of their industrial wastewater treatment plants when a potentially harmful spill or dump occurs.

2.52 Common Industrial Wastewater Variables

2.520 Flow

Flow measurements are a basic requirement at every treatment plant. Recorded flow data are essential because these records allow you to establish correct operating guidelines (loadings) and determine if your treatment plant is properly sized to process the hydraulic loads.

In many industrial production facilities, the wastewater flows are generally higher during the day-shift hours of Monday through Friday. Significant flow reductions may be anticipated in the evening hours with possible "zero" flow conditions during weekends, holidays, and annual production maintenance shutdown periods.

In cases where flows to your treatment plant approach or exceed the hydraulic design capacity, every effort should be taken to implement a production facility pollution abatement program to reduce water consumption and minimize waste generation through proper management of processing and production operations.

2.521 pH

The pH of production facility wastewaters may vary from 2.5 to 13.0 depending upon the production being processed and the type of operations conducted within the facility. Natural waters generally have pH values between 6.5 and 8.0.

If the wastewater pH varies greatly from neutral (7.0), the wastewater should be adjusted (neutralized). Neutralization may be accomplished in a tank of sufficient detention time (15-20 minutes). Sulfuric acid (to lower pH) or caustic (to increase pH) addition to the waste stream may be controlled with pH probes and controllers for rough and fine pH adjustment.

2.522 BOD and Suspended Solids

The BOD test is the rate of oxygen uptake from the wastewater by microorganisms in biochemical reactions. These microorganisms are converting the waste materials to carbon dioxide, water and inorganic nitrogen compounds. The oxygen demand is related to the rate of increase in microorganism activity resulting from the presence of food (organic wastes) and nutrients. Microorganism activity may be hindered in some industrial wastes due to the presence of toxic wastes. Industrial wastewaters may contain levels of BOD from 500 to 10,000 mg/*L*.

Suspended solids information may be used to determine the quantity of solids which will require removal in the activated sludge treatment system. Typical suspended solids concentrations for industrial wastewaters vary from 125 mg/*L* to 3,000 mg/*L*.

For any waste, the concentrations of pollutants can be readily reduced by simply using more water, but the increase in volume will result in the same number of total pounds of pollutants. The organic load, consisting of both BOD and suspended solids, can only be effectively reduced by reductions in pounds of pollutants generated at production facility sources.

2.523 COD

Chemical oxygen demand (COD) is an alternative to biochemical oxygen demand (BOD) for measuring the pollutional strength of wastewaters. When considering the use of COD for measuring the strength of wastewater, you must bear in mind that the BOD and COD tests involve separate and distinct reactions. Chemical oxidation measures the presence of carbon and hydrogen, but not amino nitrogen in organic materials. Furthermore, the COD test does not differentiate between biologically stable and unstable compounds. For example, cellulose is measured by chemical oxidation, but is not measured biochemically under aerobic conditions.

The primary disadvantage of the COD test is its susceptibility to interference by chloride. Thus, wastewaters containing *HIGH* salt concentrations, such as brine, cannot be readily analyzed without modification.

2.524 Nutrients

Aside from carbonaceous organic matter (which is measured largely as BOD), the nutrients required for reproduction of microorganisms are nitrogen (N) and phosphorus (P). In unusual cases, other elements may also be critical. These other essential nutrients include iron, calcium, magnesium, potassium, cobalt, and molybdenum. Since many production facility wastewaters are deficient in nutrients for biological treatment, nutrients can be added to optimize your biological wastewater treatment system efficiency.

The amount of these nutrients required for a treatment process depends both on the age of the microorganisms and the numbers of cells generated (growth rate) during the reduction of BOD. A BOD/nitrogen/phosphorus ratio of 100:5:1 is usually adequate. However, high-rate systems with no available nitrogen or phosphorus in the wastewater may require a ratio of 100:10:2. Ratios lower than 100:5:1 may be adequate for aerated ponds and systems with a very long sludge age. All nutrients need to be in a soluble form to be used by the microorganisms.

2.525 Toxicity

The most common causes of wastewater toxicity are excessive amounts of free ammonia, residual chlorine, detergents, paints, solvents, and biocides. Other wastes that can upset microorganisms include heavy metals, chlorinated hydrocarbons, petroleum products, acids, bases (caustics) and temperature changes. These toxic materials can enter the wastewater stream through indiscriminate dumping, improper handling of toxic materials, leaking vessels and pipes, or accidental spills.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

2.50A List three types of industries whose wastes could be treated by an activated sludge plant.

2.51A What factors influence the character of industrial wastewaters?

2.52A How would you attempt to solve a hydraulic overloading problem at an industrial wastewater treatment plant?

2.52B How can the pH of an industrial wastewater be adjusted (1) upwards, and (2) downwards?

2.52C Chemical oxidation (COD) measures the presence of (1) ____ and (2) ______, but not (3) ______ in organic materials.

2.52D List the three major nutrients required by microorganisms and four other elements that might be critical.

2.52E What are the most common causes or kinds of toxicity in industrial wastewaters?

2.53 Flow and Pre-Treatment Considerations

Because industrial wastewater characteristics may change significantly over a given period of time, a program for sampling, testing, and measuring the flow is essential.

Variations in production activity will change wastewater characteristics. Samples should be collected during each operating shift and during different stages of the finished product and raw product runs. Flows should be monitored continuously, even during cleanup and on weekends.

Daily or seasonal shutdown and start-up of a processing/production facility usually causes wastewater characteristics to vary greatly. This variation often causes problems in a treatment system. Biological treatment systems perform best on a uniform supply of a given source of food (BOD). If the food supply changes greatly, the biological process may not be able to adjust to the change. The impact of frequent shutdowns and start-ups on a treatment system should be carefully evaluated. Flow regulation procedures using holding tanks may be necessary to smooth out the flows (see Section 2.531, "Flow Control").

2.530 Flow Segregation

Considerable treatment cost savings may be achieved by processing only the wastewaters that contain pollutant materials in quantities exceeding the limits set forth in your local, state, or federal discharge permit. Consider classifying the processing/production facilities wastewaters into three categories (i.e., low strength BOD, medium strength BOD, and high strength BOD). You may find that it is possible to reuse the low strength BOD waters for cleanup purposes or dispose of it by discharge directly to a sanitary sewer system, by spray on fields, or by irrigation of pasture land.

Treatment of the medium strength BOD wastewaters (usually resulting from cleanup) may be possible by using a screen system to remove large solids and then processing the wastewater through an air flotation unit, plate and frame filter press or similar device. Since only 30 to 40 percent BOD and suspended solids reductions may be obtained from this treatment method, the dewatering process effluent (low in BOD/SS) may then be routed to the activated sludge system and will aid in diluting the high strength BOD wastewaters.

2.531 Flow Control

If your treatment plant experiences wide flow variations, these variations often cause problems in a treatment system. Depending on the daily operating mode of the processing/production facility, variations in instantaneous flow can be from very small to very great (a maximum of ten times the minimum). Each facility is obviously different, but large variations in flow may be smoothed with a surge or storage tank of about 10 to 20 percent of the total daily flow volume. Settling of solids will be a significant problem in a tank of this size, so that tank must either be mixed or some means must be provided for solids removal.

Control measures for water use in the process/production facility should be implemented. One of the most important methods of water use reduction is a complete and comprehensive training program of everyone involved in process/production. Additionally, roof gutters, downspouts, and facility storm drains may discharge to the treatment plant. These should be relocated and/or rerouted to appropriate drainage systems to eliminate charges for treating this water.

2.532 Screening

Discrete waste solids (such as trimmings, rejects, corn meal, and pulp) are effectively separated from the wastewater flow by various types of screens. Screening has many objectives including recovery of useful solid by-products; a first-stage primary treatment operation; or pretreatment for discharge to a municipal wastewater treatment system.

Screens should be located as close as possible to the process/production producing the waste. The longer the solids are in contact with water and the rougher the flow is handled (more turbulent), the more material will pass through the screens and the more the solids will become dissolved.

2.533 Grit, Soil, Grease, and Oil Removal

Fruit and vegetable, meat and fish, paper, and petroleum processing/production introduce large amounts of grit, soil, grease and oil to the waste stream. This material will accelerate equipment wear, settle in pipelines, accumulate in the treatment system, and create odors if not removed.

An aerated tank or lagoon can be provided to remove these wastes from the waste stream. This aeration system is usually designed to pre-aerate the wastewater while it aids the release of free and emulsified grease for surface collection. Additionally, separation and settling of grit, soil, and oil sludge are accomplished.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

2.53A How often should samples from industrial wastewaters be collected?

2.53B How can large variations in flow be reduced?

2.53C What kinds of waste solids can be effectively removed by various types of screens?

2.53D Why should screens be located as close as possible to the process/production producing the waste?

2.534 Central Pre-Treatment Facilities

Microorganisms that treat wastes in the activated sludge process will not work unless they are provided a suitable environment and are properly acclimated (adjusted to the wastes). A suitable environment may be provided by treating undesirable or toxic constituents in industrial wastes at the source where they are produced or at a central pretreatment facility (Figure 2.14).

Frequently the most economical method of treating toxic or undesirable wastes is at the source. If possible, do not allow these wastes to enter the plant wastewater or if they do, treat the waste in as concentrated form as possible, before it becomes diluted with other wastewaters. Source pre-treatment is appropriate for extreme pH levels, inert suspended solids, oil, grease or toxic materials (such as heavy metals).

Figure 2.14 shows a typical industrial pretreatment facility. The processes and the order of treatment will depend on both the type of industry and waste constituents. The first process is pH adjustment. Many manufacturing processes produce either high or low pH waste streams on either a continuous or batch basis. If source pretreatment does not reduce these pH variations to within acceptable ranges, central pH control facilities must adjust the wastewater pH to near neutral levels. Neutralization chemicals may be added and mixed in pipelines or in neutralization tanks. Figure 2.14 shows the pH adjustment process before the equalization tank. Some plants adjust the pH after the equalization tank. Location of the neutralization process depends on the type of industry and type of wastes being treated. See Chapter 6, "Industrial Waste Treatment," Section 6.3, "Neutralization," *INDUSTRIAL WASTE TREATMENT,* for more details.

Industry frequently uses special screens and microscreens to remove floatable and settleable solids instead of using primary clarifiers. These coarse or large solids are usually removed before the flow equalization tank. Removing these solids now will reduce unnecessary clogging and wear on downstream pipes, pumps, aerators and clarifier mechanisms. Also this process will help avoid odor problems that could develop from the settling out of solids in the equalization and emergency basins. For more information see Section 6.2, "Screening and Microscreens," in Chapter

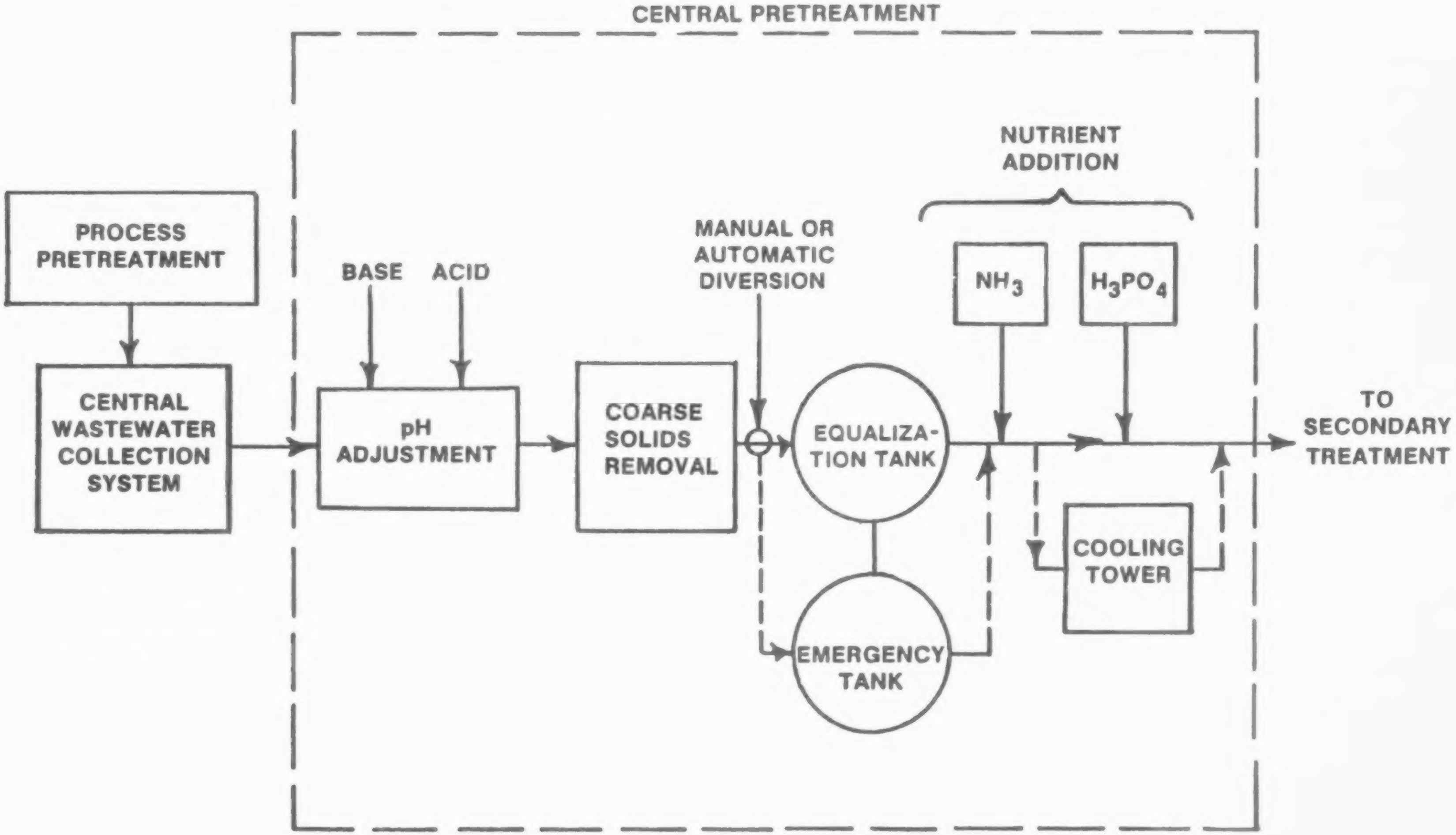

CENTRAL PRETREATMENT
PROCESS PRETREATMENT
CENTRAL WASTEWATER COLLECTION SYSTEM
BASE
ACID
pH ADJUSTMENT
COARSE SOLIDS REMOVAL
MANUAL OR AUTOMATIC DIVERSION
EQUALIZATION TANK
EMERGENCY TANK
NUTRIENT ADDITION
NH_3
H_3PO_4
COOLING TOWER
TO SECONDARY TREATMENT

Fig. 2.14 Control of the influent hydraulic and organic loading to the secondary biological treatment process

6, "Industrial Waste Treatment," *INDUSTRIAL WASTE TREATMENT.*

Biological treatment processes work best if they receive fairly constant hydraulic and organic loadings. Equalization and emergency tanks are used by industry to store peak loads for release and treatment during periods of low loadings. Fluctuating flows (hydraulic loads) are usually smoothed out by allowing all wastewater to flow into the equalization tank and by pumping the wastewater to be treated out of the equalization tank at a constant flow rate. Variations in organic loadings are smoothed out by mixing the wastewater flowing into the equalization tank with the water already in the tank. By the use of effective mixing (such as with propellers, stirrers or aeration), the organic content of the wastewater in the equalization tank can be kept fairly constant, thus providing a constant organic load to the activated sludge process.

Emergency basins or storage tanks are usually kept empty or almost empty so that there is plenty of room to store any process spills or wastewater diverted when treatment processes are upset. Wastewater may be diverted automatically on the basis of signals from continuous monitoring equipment (total organic carbon, pH, or conductivity analyzers). Also diversion can be done manually based on results from continuous analyzers, grab samplers, or from a verbal warning of upset conditions from process operating personnel.

Generally, continuous monitoring and automatic diversion is the ideal approach for detection and isolation of process upsets. Unfortunately, continuous monitoring produces some severe operational problems in the form of sampling system and analyzer difficulties. Solids can plug the sampling lines and the analyzers may require considerable maintenance. To avoid these problems, some plants rely on the analysis of grab samples and notification by process operators when spills occur. Whether you use continuous monitoring or grab samples to detect spills and undesirable influent conditions, you must protect your biological treatment processes from unsuitable conditions.

Frequently industrial wastewaters lack the proper amounts of nutrients for proper microorganism growth and reproduction in the activated sludge process. The major nutrients of concern are nitrogen and phosphorus. Other nutrients such as calcium, magnesium, sodium, potassium, iron, chloride, and sulfur are needed by the microorganisms, but sufficient quantities are usually found in most process waters.

Nitrogen and phosphorus are needed for biological growth and reproduction in quantities approximated by a $BOD_5 : N : P$ ratio of 100:5:1 or a COD : N : P ratio of 150:5:1. If the nitrogen or phosphorus levels in the wastewater being treated are less than the values indicated by these ratios, more nitrogen can be added in the form of ammonia (usually as 30 percent aqueous) and phosphorus as phosphoric acid (usually as 75 percent aqueous). When these nutrients must be added, they are metered into the wastewater from the equalization tank or recycle sludge streams before the aeration tank. The additions are based on the difference between the desired amount and the actual amount in the wastewater being treated.

When the wastewater being treated has been heated by a production process, the water may have to be cooled before biological treatment, especially during the warmer summer months. Biological activity and treatment effectiveness usually drops rapidly at water temperatures above 99°F (37°C). Cooling towers are sometimes installed where heated discharges can cause problems. Usually a portion of the influent flow, or in extreme cases, the entire influent flow, is directed over the cooling towers during the warmest summer months. Proper operation of these towers allows sufficient evaporative cooling for control of the aeration basin temperature.

Sometimes sufficient water cooling will occur from aeration in the equalization and aeration basins. Mechanical aerators can be especially effective. Diffused air aeration systems, however, can increase the temperature by 5 to 7°F (3 to 4°C) because of the hot air from the blowers. If excessive cooling is caused by surface aerators in the cold winter months, shut down the aerators (if possible) or add heat by using heat exchangers or steam.

Troubleshooting problems in central pretreatment facilities are similar to other treatment processes. If a spill occurs with a high initial oxygen demand, mechanical aerators may not be able to supply enough oxygen to maintain a minimum dissolved oxygen (0.5 mg/*L*) in the equalizing basin. When this happens, the basin may become septic and give off undesirable odors. If the aerators cannot deliver more oxygen, additional oxygen may be provided in the form of hydrogen peroxide.

Another possible problem with mechanical floating aerators is excessive cooling of the wastewater during cold winter months. If the water temperature becomes too low, the activity of the activated sludge organisms and the performance of the secondary clarifier may be reduced greatly. A partial solution to this problem is to shut off some of the aerators completely or to shut off all of the aerators periodically. You must keep the contents of the equalizing basin well mixed to avoid surges of waste organic loads or solids settling on the bottom of the basin. If a proper schedule is developed for turning the aerators on and off, you can provide sufficient mixing and keep the heat lost from the surface of the basin low.

If the aerators fail, carefully monitor the flows from the equalizing basin to the aeration tank using continuous analyzers or frequent grab samples. If the variation in organic loading, hydraulic loading or temperatures becomes much greater than normal, divert all or some of the flow to the emergency basin. When the aerators are returned to operation, the flow to the aeration basin should be increased gradually to avoid shocking the biological system.

When the nutrient flow stops, try to get the flow back on line as soon as possible. If the nutrient flow can be restarted in 24 hours or less, feed nutrients at twice the normal rate for the same period of time that the nutrient flow was off. If the nutrient flow will be off for more than 24 hours, try adding nutrients from bags such as agricultural or garden fertilizers.

2.535 Start-Up or Restart of an Industrial Activated Sludge Process

Once the wastewater has been properly pretreated and ready for the activated sludge process, the activated sludge biological culture must be ready to treat the wastes. Whether you are starting a new activated sludge process or trying to get an existing process back on line after the culture has been wiped out by a toxic waste, the procedures to develop a new activated sludge culture are similar.

New activated sludge cultures are started by obtaining "seed activated sludge" or activated sludge microorganisms from either a nearby municipal or industrial wastewater treatment plant. The amount of seed activated sludge needed depends on the hydraulic and organic loadings on your treatment plant. The greater the load, the more tank trucks of activated sludge seed will be needed.

Once the activated sludge seed has been added to the aeration basin, the level of the water in the aeration basin is usually maintained just below the overflow level. The aeration system is in operation. You want to increase the population of activated sludge microorganisms. This is accomplished by feeding the "bugs" a solution they can eat quickly and use efficiently for building more microorganism cells. The most common chemical feed is sodium acetate. These microorganisms also require nutrients for fast and healthy growth. The key elements are nitrogen and phosphorus. They also must be provided in the form of chemicals added to the wastewater. Usually ammonium sulfate and potassium dibasic phosphate (available in a dry form in bag quantities) are used because they are relatively pure and can provide an adequate buffer for pH control in the aeration basin. These chemicals are easily dissolved in small amounts of water.

Start-up procedures will vary with each industrial waste treatment plant. Usually the chemicals are added to achieve a ratio of COD : N : P of 150:5:1 or BOD : N : P of 100:5:1. Chemicals are added on a batch basis directly to the aeration basin (or indirectly through pump wells) until the microorganisms multiply to approach a MLSS level of 2,000 mg/*L*. Usually enough sodium acetate (food) is added in a batch to allow the bugs to feed for one to three days. Between batch feedings, periodic analyses of the aeration basin contents will indicate the rate at which the bugs are consuming the organic materials (oxygen uptake rate readings and filtered COD or TOC analyses) and the rate of growth of the bugs (MLSS analyses). These measurements will indicate the timing for future batch feedings. Experience indicates that you usually have to feed chemicals for about one week to produce a flocculating sludge.

Once a MLSS level of over 2,000 mg/*L* has been reached, the industrial wastewater may be introduced into the aeration basin. *THIS STEP MUST BE VERY GRADUAL.* Pump approximately 10 percent of the total industrial waste flow from the equalizing basin. Chemical feeding should be continuous if at all possible. This procedure allows the activated sludge microorganisms to slowly adapt or become acclimated to the industrial wastes so the wastes will not shock the delicate growth patterns of the activated sludge microorganisms.

Periodically take samples from the aeration basin in order to monitor the degree of biological growth and removal of organic wastes (oxygen uptake rate, MLSS, and filtered COD). After two or three days, if the monitoring results are favorable (i.e., high COD removal, MLSS increasing, oxygen uptake rates steady), the industrial waste flow input can be increased (20 to 25 percent of the total flow) and the chemical feed (food) can be reduced by a similar amount. Also, at this time, the permanent nutrient feed system (if any) should be started to assure an adequate supply of nitrogen and phosphorus.

This procedure is followed until all of the industrial wastewater flow (with no chemical feed) is being fed to the activated sludge process. The time for the acclimation process to be complete will vary with the industrial wastes being treated, but usually two to three weeks are required. Once the activated sludge process starts to generate excess activated sludge above the desired MLSS level, sludge wasting should be started to control the MLSS.

Portions of this section were taken from *BACKGROUND DOCUMENT, DU PONT ACTIVATED SLUDGE TREATMENT.* Permission to use the material in these two sections is sincerely appreciated.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

2.53E In general, where is the most economical location to treat toxic wastes?

2.53F Why do some industries require a waste pretreatment facility?

2.53G Why does industry use screens to remove coarse solids?

2.53H How can variations or fluctuations in influent organic loadings be smoothed out before the aeration basin?

2.53I What chemicals are used to provide nutrients in the form of nitrogen and phosphorus?

2.53J Where would you obtain a "seed activated sludge" to get an existing activated sludge process back on line after being wiped out by a toxic waste?

2.53K Why must industrial wastes be added gradually to the aeration basin initially?

2.54 Operational Considerations (Activated Sludge)

The following discussion will center on specific operational problems experienced at various industrial wastewater treatment plants. Corrective action methods are also presented.

2.540 Neutralization

pH control systems may be installed to treat various process/production wastewaters. pH adjustment of this nature is usually done as a pretreatment process. However, lime, alum, and iron salts may be used in a pre-secondary chemical clarification process. In this case it is necessary to provide additional pH adjustment facilities to neutralize the normally high pH effluent (8.5 to 11.0) from the chemical clarification process. Abnormally high wastewater pH will result in loss of activated sludge system efficiency and cause settling problems in the secondary clarifier. A consistently alkaline waste (high pH) can be neutralized by using carbon dioxide (CO_2). Boiler stack gas and a compressor delivery system could be a source of carbon dioxide.

If a high pH wastewater is a problem because you use lime, alum or iron salts as a settling aid, consider the use of polymers instead.

If the pH is too low (acid), the pH can be increased by the addition of lime ($Ca(OH)_2$) or caustic soda (Na OH). The activated sludge process usually operates satisfactorily in a pH range from 6.5 to 8.0.

2.541 Nutrients

Nutrients, especially nitrogen and phosphorus, can be critical in the performance of the activated sludge system. The exact point at which nutrients become critical depends on your type of treatment process and how you operate it.

Remember that all applied nutrients must be in a soluble form to be used by the microorganisms. The addition of nutrients should be accomplished at a point where the incoming wastewater is highly mixed, preferably in the aeration basin.

The quantity of nutrients added to the treatment system should be based on the desired BOD reduction and the amount of the nutrient deficiencies. The amount of nitrogen and phosphorus required to treat a waste can be estimated from the quantity of sludge produced per day. The pounds of nitrogen required per day is equal to 10 percent of the volatile solids (on a dry weight basis) produced each day. Phosphorus requirements are one-fifth the nitrogen requirements. The amount of nutrients which have to be added each day is determined by the difference between the quantity required and the quantity available in the wastes.

Typical supplemental nitrogen is provided by using aqueous ammonia or anhydrous ammonia. Supplemental phosphorus is provided by using dissolved triple superphosphate, phosphate fertilizer, or phosphoric acid (a waste acid from aluminum bright dipping facilities).

When the supply of nitrogen and phosphorus from the wastewater is below that required by the microorganisms in your biological treatment process for extended periods of time, filamentous organisms may begin to predominate and cause sludge bulking in the secondary clarifier.

2.542 Daily System Observations

Daily observations of the bacterial population must be made to observe developing system changes and stress conditions so that proper action may be taken before overall treatment efficiency is affected. Under normal conditions, the bacterial population is composed primarily of small bacteria with large numbers of stalked ciliates and many free swimming ciliates and rotifers (Section 2.32). The presence of these higher forms gives you the indication that the process is operating properly. The following conditions have been found to cause the disappearance of the higher forms.

1. DO levels below 3.0 to 4.0 mg/*L*: With a high mixed liquor solids, it is possible that the oxygen transfer efficiency is impaired at lower DO concentrations. Additionally, filamentous growth may predominate.
2. High organic loadings: When the process is in the dispersed growth phase, it has been observed that the higher forms do not compete as well as the simpler bacterial forms.
3. Toxic substances or nutrient deficiencies: These conditions will affect the growth and maintenance of the higher forms.
4. pH control: If the pH control system is not operating properly to adjust the pH to near neutral, ciliates and rotifers will not adapt to pH fluctuations and will disappear.

2.543 Return Activated Sludge (RAS)

In most cases the RAS values for industrial waste treatment systems are the same as for municipal systems as discussed in Section 2.2. However, some systems experience a sludge with low compacting characteristics (high SVI). This is usually, yet not always, the result of conditions shown in Section 2.23, Table 2.3, on page 58.

2.544 Waste Activated Sludge (WAS)

An activated sludge plant, operating at a high rate (or low sludge age) will produce 0.5 to 1.0 pounds of microorganisms for each pound of BOD removed. In addition to the production of up to 0.5 pounds of microorganisms per pound of BOD removed, added sludge results from the non-biodegradable suspended solids, both volatile and nonvolatile, in the influent to secondary treatment. Consequently, it is common for the total secondary sludge production to be 0.8 to 1.0 pounds per pound of BOD removed. Sludge from secondary treatment systems is still biologically active and will putrefy. This can cause an intolerable odor. If the sludge contains no domestic wastes, it may be possible to spread and dry the sludge quickly on a disposal site or agricultural land, and then plow it into the soil.

Secondary sludge is difficult to dewater as compared with primary sludge. Raw, undigested secondary sludge has a total solids content of only one-half to one percent in air systems and one to three percent in pure oxygen systems. In addition, the cellular matter in the sludge is only fifteen percent solids. Unless the cell membranes are ruptured, microorganisms cannot be dewatered to greater than ten percent solids. Cells can be ruptured by heating or slow freezing although natural freezing can be used in some climates.

An alternate method of handling WAS from a treatment system that operates seasonally is to divert WAS to a lagoon. At the end of the season, the solids from the lagoon are periodically returned to the aeration system for "complete" oxidation during the off-season period.

2.545 Clarification

In industrial waste treatment systems, sludge settling often is significantly affected by influent characteristics variations. As a result of these variations, the settling characteristics of the sludge are extremely critical. Therefore, clarification rates of less than 400 gpd/sq ft (16 cu m per day/sq m) may be necessary to obtain proper operation.

If you observe a gradual decrease in percent solids removal over a period of time, this reduction may be the result of grit and silt accumulation in the aeration basin. The grit and silt are not carried out in the effluent, remain in the basin, and reduce aeration volume and detention time. A higher volatile content of the sludge would be indicative of this condition. A lower volatile content would occur only if the aeration basin's contents are well mixed. In this case there should be no settling nor accumulation of grit and silt.

If this condition exists, make every attempt to increase the efficiency of your grit removal process. If you do not have grit removal facilities, make every effort to increase the mixing in the aeration system to prevent the settling of solids in "blind" or "dead" areas (typically corners). If none of the above control methods are available to you, consider cleaning your aeration basins on a yearly basis if necessary. If you operate a municipal treatment facility and find grit and silt are coming from an industrial source, make the industry remove the grit and silt by pretreatment methods. Industry should not be allowed to dump this material into a sewer.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

2.54A Where should nutrients be added to a wastewater?

2.54B List some typical sources of supplemental nitrogen and phosphorus.

2.54C What factors or conditions have been found to cause the disappearance of higher forms of microorganisms from the activated sludge process?

2.54D What items could cause a *GRADUAL DECREASE* in percent solids removal from an activated sludge process over a period of time?

NOTICE

The following Sections 2.55 through 2.58, were prepared by the operators of actual industrial wastewater treatment plants. These operators have described procedures they use to treat industrial wastes by the activated sludge process. You must remember that there are many types of industries and that the waste flows and constituents will be different at every treatment plant. The intent of the following sections is to provide you with ideas that might work for your industrial waste treatment activated sludge plant.

2.55 Pulp and Paper Mill Wastes by James J. McKeown

STOP POLLUTING
STOP POLLUTING
STOP POLLUTING
STOP POLLUTING
STOP POLLUTING
STOP POLLUTING

Industrial wastewater treatment plants are designed in much the same manner as municipal plants; however, there are some important differences in treating pulp and paper mill wastes. Before any waste stream can be treated, both the average and range of fluctuations of flows and waste constituents must be measured, recorded and analyzed.

2.550 Need for Recordkeeping

The format for recordkeeping will usually be prepared by the environmental control supervisor. There are three basic reasons for keeping accurate records.

The first reason is to keep a history which helps troubleshoot problems which arise. Each entry onto the log sheet is made at the frequency needed to help locate trouble. Even so, the operator needs to be alert for trends which occur in between the log entries. Most log sheets call for pertinent remarks and the operator should make use of this column to note unusual conditions or to simply enter "all's well." Your record will be read by the person relieving you in order to pick up the operation. You know the things most helpful to you when starting a shift and it's simply a matter of doing likewise for your relief.

The second reason has to do with accounting for the operation of the plant during appropriate times, such as, weekly or monthly. If the operator should fail to make an entry and must estimate a value, the value should be footnoted accordingly. Failure to enter even routine data may prevent a calculation from being made. Serious mechanical problems or chronic symptoms of future problems should also be noted so the work orders can be issued to correct the problem.

The last reason is that records are legal documents which will protect the company from unjust claims. In other words, the company may have to prove that its operations were normal during a certain time period. The only way this can be accomplished is by use of the actual operating data. Therefore, it is very important to keep accurate records. Don't forget that all recorder charts are also a part of the official record. You may be asked to make notations on these charts as part of the accounting procedure and it's usually a good idea to initial the note. Another good idea is to make a note on your log sheet each time you mark the recorder chart.

2.551 Wastes Discharged to the Plant Collection System

In most industrial systems, departments or small networks of sewers are monitored individually. The control of wastewater in these networks is often the responsibility of production personnel. Experienced production personnel know that certain conditions in their area will result in abnormal discharges to the sewer. With proper communications between operating and waste treatment plant personnel, an alarm can be sounded either before or right after a spill actually happens. A quick phone call will allow emergency measures to be implemented in time to prevent operating problems. Everyone must encourage the necessary communications to give waste treatment personnel all the advance notice they need to properly operate the plant.

Several key sewers may be monitored continuously. In such a system the wastewater treatment plant operator can usually read the recorders to see if all the sewers contain normal quantities of wastewater. The use of centralized instrument panels both in the mill production area as well as the treatment plant will allow confirmation of a particular condition.

Operators should understand the reason why each water quality indicator is being monitored and if necessary, how the sensor works. In highly automated systems, the operator may use instrumentation personnel in order to maintain the proper calibration and operation of each sensor. However, even in this case, a basic understanding of the instrument or electrode is useful.

The most common control sensors which are used in pulp and paper mills are conductivity, flow, pH and turbidity. Special situations may be monitored to determine temperature, color, sodium, COD, TOC, or TOD. Oxygen respiration may also be monitored to detect overloads or spills. Continuous bioassays may be required at certain installations and DO is used to control aeration in activated sludge plants. Treatment plant personnel should be aware of the meaning of changes in the values of each water quality indicator at each sampling point.

The operator should be familiar with certain mill waste flow and constituent recorder patterns (variations) which are likely to occur in each sewer, so that appropriate control actions can be initiated. For example, a modest increase in conductivity accompanied by a low pH indicates that acid is probably being discharged into the mill sewer. However, if both conductivity and pH are quite high, then an organic discharge containing black liquor is the likely event. Further, if flow measurement is available, the operator should be able to determine the potential severity of the discharge. The operator should know what combinations of readings to look for and what actions are necessary in each case to control the situation. Many mills use continuous recorders with signal alarms to alert the operators that a particular sewer is exceeding its normal limit. However, whether communication is automatic or by person to person contact, most situations have a history of occurrence and can be properly handled using predetermined control measures.

If a spill is detected by the sensor system, the operator should be able to verify the spill. A phone call to the mill operating area may be sufficient to learn how long the event is likely to continue. With this information, a decision can then be made on the procedures to use to control the spill. Industrial control systems often use emergency storage tanks or spill ponds which can be filled quickly to protect the treatment plant.

Knowledge about the nature and duration of an emergency upset is a necessity for proper management of reserve storage capacity. These diverted wastes can later be bled into the treament plant at controlled rates.

2.552 Variables Associated with the Treatment of Paper Mill Wastes

NUTRIENT CONTROL

The wastewater usually does not have enough nitrogen and phosphorus to support bacteriological growth. Thus, facilities are often installed to add these nutrients to the wastewater before biological treatment. The proper amounts of these nutrients must be added because too little or too much may create problems. The operators should be familiar with their nutrient feeding systems and in cold climates, the temperatures at which certain nutrient chemicals will freeze. Many wastewaters only require nitrogen addition because there is enough phosphorus in the wastewater as a result of boiler water corrosion control and cleaning operations.

Experience with BOD removal at the lowest possible nutrient addition rates will allow the operator to properly control the addition rate. Soluble ammonia nitrogen and phosphorus generally need not exceed 0.5 and 0.25 mg/*L*, respectively, in the final effluent. Many systems are providing adequate treatment at effluent concentrations of 20 to 50 percent of these values. If final effluent nutrient values are considerably lower than these values, then additional nutrients may be necessary.

FOAM CONTROL

Another additive in pulp mill wastewater systems is a defoamer. Some pulp mill effluents foam because the wood soaps are not fully captured in either the tall oil or recovery systems. The chemicals which cause foams are oxidized during biological treatment. However, if foaming isn't controlled in the biological plant while treatment is taking place, a variety of problems may result, including frothing of mixed liquor solids thereby removing these solids (organisms) from the system. Foam can also engulf and shortout motors and other electrical equipment. Also, foam will cause certain level recorders to misinterpret the true liquid level and this can be troublesome if flow measurement is affected. Foam may also cause an air pollution problem, especially if it dries and becomes windborne.

Foam is generally controlled by water sprays or dosing with an antifoam chemical. The object of either approach is to cause an uneven distribution of surface tension in the foam. The spray also provides a physical impact which busts the foam and creates channels for subsequent drainage through the foam.

Defoaming chemicals are very expensive and their applications should be carefully controlled. The delivery system can be by overhead spray or by using the aerator to distribute the chemical into its own spray. Either system has been used with success in the paper industry. Most paper mills use metering pumps to feed defoamer. The chemical is added continuously at a predetermined rate. If foam volume increases, the chemical dose is increased for a short period of time and then reduced to the baseline again. Excessive use of defoamers may also place an added oxygen demand on the system which is undesirable. Automatic systems respond to conductivity or photoelectric sensors. When the foam reaches the sensor, the defoamer chemical is applied in steps until the foam recedes below the sensor. Chemical suppliers will gladly recommend procedures which reflect their experience.

pH CONTROL

The plant may be equipped with a neutralization system where acid or caustic is added prior to the mixed liquor tank. Most facilities add these chemicals prior to the primary clarifiers. However, some plants bypass the clarifiers with large volumes of bleach plant wastes and, in this case, pH adjustment is accomplished in a blend tank where bypassed wastes join primary effluent.

Hydrated lime, $Ca(OH)_2$, and caustic, NaOH are two of the common alkaline solutions used to increase pH while sulfuric acid, H_2SO_4, is the common acid solution. Control of pH variations is probably more important than the actual pH value. However, most mills have a high and low pH target value which must not be exceeded and pH should be adjusted to fall within this range.

Most pH control systems are automatic and are based upon pH and flow sensors placed downstream from the blending point. Acid and caustic make up requires that the operators follow prescribed safety rules because of the danger involved in handling these concentrated chemicals.

PRODUCT RELATED SITUATIONS

Treatment of pulp and paper mill wastewaters is similar in many ways to the treatment of municipal wastes. The machinery is identical in many cases. However, the operator who worked in a municipal plant will quickly become aware of some additional differences which depend on the type of pulp and paper being produced. These differences are reviewed here.

The paper industry has several types of pulp mills and manufactures a large number of grades of paper. To a large extent the waste treatment systems operations will reflect the particular mix of pulp and paper being made each shift. Thus, a knowledge of which grades are being produced can be an important factor in the operation of the plant. We cannot cover all of these product related differences in this section. However, the topics of flow, settleable solids, color, and odor can be discussed in general terms.

1. *FIBER* — The paper industry manufactures products made primarily of cellulose. The cellulose must be treated in the mill in a variety of ways which include cleaning, blending, refining, screening, bleaching, trimming, and drying. In many of these operations, the cellulose is pumped from one unit process to another. In order to efficiently process the cellulose into paper, the fibers must be separated (diluted) for some unit processes and matted (molded) for others. The result is that the cellulose is contacted with large quantities of water at various points in the process.

   This water is later removed from the cellulose and much of it is reused. The recycle system in a paper mill actually retains 3 to 10 times the amount of water sewered. The paper industry is continually looking for new ways to reuse much of this water. In many cases, the mill uses internal treatment to renovate these waters before reuse in showers or for stock dilution.

   Also, the effluents are generally treated within the mill before being discharged to the sewer. Most of the usable fiber is scalped from the water by a variety of savealls. The savealls may be screens, filters of various sorts, dissolved air flotation units, or mechanical clarifiers. See Chapter 28, "Industrial Waste Treatment," for details on these processes.

   When the recycle system is working properly, the treatment plant receives moderate quantities of water containing the fine cellulose particles and dirt which have been deliberately separated from the paper. However, when the recycle system is out of balance, large quantities of water and cellulose may be sent to the sewer.

   Most of these cellulose fibers settle readily and will clog screens and impair the passage of effluent if adequate mixing or dilution isn't maintained in the sewers. Further, when the fibers reach the primary clarifier, they settle readily and increase the load on the rakes. Most clarifiers are designed to handle this load without overloading, but the sludge removal rate is usually increased to keep the torque in control.

2. *FLOW* — Large quantities of extra water may also accompany these abnormal fiber discharges. Again, the size of the plant should be adequate to handle these surges. However, the operation may require adjustment of chemical feed and use of standby pumps after hydraulic surges have reached the plant.

   Further, most paper mills operate around the clock. Thus, flows are fairly constant and don't decrease during the night as happens with the flow to municipal plants.

3. *SETTLEABILITY* — If the paper plant contains a pulp mill, some further differences may be evident. The pulping of wood separates a number of chemicals from the fiber. These chemicals are believed to cause higher SVI levels in biological sludges produced during treatment. In the case of treating 100 percent pulp mill effluent, secondary clarifiers are designed with overflow rates lower than systems processing only domestic wastes in order to accomodate this slower settling floc. Also, the final effluent may contain slightly higher suspended solids concentrations where 100 percent pulp mill wastes are being treated.

4. *COLOR AND TURBIDITY* — The chemicals extracted from wood are colored very much like swamp water which contains vegetative extracts. Thus, the wastewater will generally appear yellowbrown. A wastewater can be clear in terms of suspended solids, although it is still colored by dissolved solids. Wastewater with a dissolved color will change in color with changes in pH as well as mill operations.

   Certain papermills use dyes or pigments to color the fibers. Tissue paper, construction paper, and a variety of specialty products are examples of grades which are colored. The wastewater associated with these grades will also be colored. Mills with one paper machine produce effluents which change in color every time that the papermaker changes the dye. However, the color change isn't as noticeable in effluents from mills with many paper machines because the colors blend toward neutral and often appear gray. Most dyes are oxidized and thus disappear during biological treatment.

   Mills making filled grades or using starch will produce waters which appear white. Starch will usually degrade in biological treatment and the cloudiness and turbidity will disappear during treatment. Some mills use titanium dioxide and talc to fill the paper sheet. These very fine white particles have high refractive powers and may not be completely removed during treatment. Thus, the final effluent will contain white solids. Also, the return activated sludge may appear white because it contains large quantities of these inorganic pigments.

5. *ODOR* — The odor of the water discharged from a pulp mill will reflect the chemicals used and produced in the pulping process. In most cases, these odors are associated with gases which were captured in the process water back in the mill. When these waters arrive at the treatment plant and are aerated, the gases are stripped from the wastewater. The extent to which these gases are present in the wastewater depends on the pulping process and the extent to which the waters are stripped of gas prior to discharge to the sewer.

EMERGENCY SYSTEMS

The plant probably has some emergency features which are seldom used. Industrial systems must be able to be started up and shut down in accordance with production variations. In many cases, these are planned far enough in advance to turn down or shut down the plant in an efficient manner. However, occasionally, because of an equipment failure at the plant, personnel have to respond quickly by employing seldom used facilities. The operators should run through periodic drills which simulate their reactions to these emergencies so there will be no delay when a real emergency occurs. Examples of seldom used facilities are standby pumps, diversion valves, spill tanks and lagoons as well as feed tanks used to supply organic load to build up an activated sludge culture prior to plant start-up. Further, spill tanks should normally be operated empty so their capacity is available during an emergency. After the tanks are used to scalp a spill, they should be emptied (usually gradually) at a rate which will allow the plant to treat the wastewater adequately. However, the goal should be to empty them as quickly as possible because the plant is susceptible to upset if another spill should occur which is larger than the reserve spill capacity. The spill tank is often used to store the waste for use during the shutdown period.

2.553 Start-Up and Shutdown Procedures

The paper industry has occasion to shut down and start-up an activated sludge plant for several reasons. Holidays, maintenance (preventative and emergency), process upsets, strikes, and scheduled production reductions may require that the activated sludge plant be turned down or shut down. The procedures for shutdown and subsequent start-up vary with the nature and duration of the shutdown, as well as the weather expected during the shutdown.

For short shutdowns a set of action plans must be developed to alleviate potential problems in line with some interim goals. The goals must be selected prior to each planned shutdown.

2.554 Management of Shutdowns and Start-Ups

by W.A. Eberhardt

WHY MANAGE SHUTDOWNS AND START-UP?

The performance of an activated sludge plant improves with increasing stability in influent loadings (waste composition and volume) and environmental conditions (pH, temperature, DO). Typically, as the steady-state condition is lost, discharges of suspended solids and BOD increase. Also of significance, once lost, the favorable performance associated with steady-state operation is not quickly regained.

Shutdown/start-up conditions have a high potential for producing a loss of biological equilibrium or steady-state. In addition, shutdowns/start-ups increase the risks of personal injury and produce abnormally high operating costs due to the new or unusual conditions typically experienced.

As an operator, it is your responsibility to the environment, your employer, and yourself to prevent or minimize the potential adverse impacts of a shutdown/start-up. To adequately meet your responsibilities, you must carefully manage the situation.

WHAT IS A SHUTDOWN/START-UP?

Shutdown/start-up is a situation whereby the normal wastewater feed is interrupted, or, one or more of the activated sludge support systems (such as aeration) malfunctions. The result is that the biological process is prone to lose equilibrium. Typical circumstances surrounding a shutdown/start-up are:

A. Interruption of Normal Feed
   1. Manufacturing interruptions (weekends, holidays, annual shutdown, equipment failures)
   2. Manufacturing abnormalities (spills, process changes or tests, product changes)
   3. Feed support loss (failure of a feed pump)

B. Interruption of Biological Support Systems
   1. Mechanical failures or planned outages (recirculation pumps, aerator, chemical feed pump)
   2. Runout of a chemical (nutrient, neutralization, polymer)

HOW CAN I MANAGE SHUTDOWNS/START-UPS?

To successfully manage shutdowns/start-ups, you must have *OBJECTIVES* and *GOALS*, and a *PLAN FOR IMPLEMENTATION*.

1. *OBJECTIVES AND GOALS* — Several basic objectives to be accomplished during shutdowns/start-ups are:
   1. Maintain satisfactory/legal process performance,
   2. No personal injuries, and
   3. Maintain least cost for satisfactory performance.

   For each objective, specific goals must be established. Table 2.7 provides some suggested goals. For example, one goal toward achieving the process performance objective is to maintain a constant F/M ratio. This would prevent one or more of the potential problems cited for failure to control or change the ratio.

   YOU must customize the suggested objectives and goals to your operation.

2. *PLANNING* — The shutdown/start-up plan is a strategy to accomplish your selected goals. The plan is necessary for both scheduled and sudden occurrences. The plan may be formally typed in a manual or written in a log book. This plan should include the specific activities and associated timing and responsibilities necessary to overcome all identified barriers to accomplishing each goal. For example, the shutdown might involve discontinuance of wastewater from manufacturing — a barrier to maintaining a constant F/M ratio. Your plan might call for storage of wastewater in a basin in advance of the shutdown with provision to pump it to the process during the outage (holding wastewater in a basin at all times might be a continuing plan to cover unscheduled losses of process wastewater). Finally, your plan, as applicable, must be coordinated with other wastewater treatment *AND* manufacturing activities.

3. *IMPLEMENTATION* — Successful implementation of your plan requires:
   a. *COMMUNICATIONS* with involved and affected personnel and organizations before and during implementation,
   b. *DISCIPLINED EXECUTION* of the planned action steps,
   c. *EVALUATION OF RESULTS* during execution with appropriate plan adjustments, and
   d. *CRITIQUE* of results and performance after the incident with emphasis on learning for future improvement.

4. *SUMMARY* — The benefits of well managed shutdowns/start-ups include satisfactory and legal performance, fewer injuries, and reduced costs. To manage an interruption, you must identify its occurrence (actual or potential) and aggressively act to minimize its consequences. Success will follow if objectives and goals are established, plans are developed to achieve them, and plan implementation is coordinated, disciplined, and flexible.

2.555 The Periodic-Feeding (Step-Feed) Technique for Process Start-Up of Activated Sludge Systems[13]

by R.S. Dorr

NEED FOR EFFECTIVE START-UP PROCEDURES

Activated sludge biological treatment systems are being constructed in many locations across the country by pulp and paper mills. Process start-up of these high rate biological systems presents a complex problem. The plants currently in operation across the country prove that given enough time and attention these systems can be successfully started up. Time, however, is costly and often limited when dealing with discharge permit deadlines.

DEVELOPMENT OF THE START-UP PROCEDURE

The periodic-feeding technique which has been developed for the start-up of pulp and paper mill activated sludge systems is based upon the biological growth kinetics and physical microbiological concepts which govern the biological treatment process. Several statements are crucial to the development of this start-up procedure and are summarized below:

1. The concentration of microorganisms in the system influent (the mill sewer) is insignificant in comparison to concentrations found in domestic collection systems.
2. There exists a critical minimum mean cell residence time (MCRT) below which the system cannot function and the microorganisms cannot establish themselves.
3. The degree of flocculation of the microorganisms is influenced by the food-to-microorganisms ratio (F/M). At very high values of F/M, microorganisms are completely dispersed and will not settle, rendering the secondary clarifiers nonfunctional.
4. If the secondary clarifiers are for some reason nonfunctional, the mean cell residence time is equal to the hydraulic retention time of the aeration basins.
5. Increasing the food (soluble BOD) to a bacterial population beyond certain limits, does not necessarily increase the rate of population growth.

In view of these facts, a process start-up procedure should provide a means of controlling the food-to-microorganism ratio and/or the mean cell residence time to prevent dispersal and washout of whatever bacteria may be initially present in the system. Neither the soluble BOD concentration in the system influent nor the amount of bacteria in the system can normally be controlled during a process start-up.[14] The hydraulic load-

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[13] *This section was taken from "Development and Testing of the Step-Feed Technique for the Process Start-Up of Activated Sludge Systems," by R.S. Dorr,* PROCEEDINGS OF THE 1976 NCASI NORTHEAST REGIONAL MEETING," *NCASI Special Report No. 77-03, May 1977.* NOTE: *The original paper referred to this procedure as* STEP-FEED, *but this section uses the term* PERIODIC-FEEDING *to avoid confusion with the step-feed activated sludge process.*

[14] *As an exception, bacteria from another similar activated sludge plant may be introduced by "massive seeding" techniques involving many truckloads of thickened sludge.*

TABLE 2.7 GOALS FOR SHUTDOWNS/START-UPS

Goals	Potential Problems	Action Plans
1. Maintain constant food characteristics	Solids in effluent SVI increase Low BOD removal Lost activated sludge organisms	Normal waste — Store prior to shutdown — Feed during shutdown Abnormal wastes — Minimize — Bypass to storage for equalization
2. Maintain constant food/microorganisms (F/M)	Solids in effluent SVI increase	Pre-Shutdown — Store waste — Lower MLSS During Shutdown — Feed stored waste — Reduce or stop wasting
3. Maintain nutrient balance (N, P, metals)	Solids in effluent Bulking Low BOD removal which persists	Assure in advance — Adequate supply of nutrients — Provisions for addition of nutrients
4. Maintain environment constant (temperature, pH, DO)	Solids in effluent Low BOD removal	Optimize aeration for — DO — Heat retention in winter — Heat loss in summer Introduce heat during prolonged winter usage Assure in advance — Supply of neutralization chemicals — Provision for addition of chemicals or store pre-neutralized waste
5. Maintain hydraulic loading control	Hydraulic surges Flows during periods requiring a "dry outage" Sludge recycle imbalances	Plan together with manufacturing people Use of surge/storage basins Closed valve motivation Gradual increase in loading at start-up
6. Necessary equipment functional	Power outage (light, equipment) Instrument air outage (valve positioning)	Advance provisions — Standby generators — Instrument air override — Use storage basins
7. Complete required maintenance on schedule	Less than optimum performance after start-up Production downtime for subsequent repair	Critical path planning Maximum prework Avoid shutdown items
8. No personnel injuries	Lack of safety equipment Difficult environment (no lighting) Abnormal (non-routine) tasks Inadequate staffing	Individual job safety — Analyses with appropriate follow-up — Safety training program
9. Cost optimization	Shutdown extension due to — Inadequate staffing Undertaking necessary work Provision of unnecessary equipment (generator for aerators)	Question shutdown needs Complete planning
10. Protect receiving stream	Spills Inadequate treatment	Comprehensive planning
11. Meet permit requirements	Inadequate performance and/or discharge monitoring	Meet all goals in this table

ing rate, however, can be regulated. This is the basis of the start-up procedure described in this section.

Assume a waste stream of 10 MGD and 100 mg/*L* soluble BOD were to be treated in an activated sludge plant designed to have a hydraulic retention time of six hours. Flow is introduced to the system along with normal amounts of nitrogen and phosphorus required, and aerators and recycle pumps are started. After the six hours of flow required to fill the basins and clarifiers, the following conditions exist:

1. The soluble BOD level throughout the system is 100 mg/*L*.
2. The amount of bacteria present is very small, existing only in the form of "seed."
3. The value of F/M is very high, and therefore the bacteria are totally dispersed.

At this point, the flow through the system could be allowed to continue at 10 MGD; however, this might be disadvantageous for two reasons. The "seed" microorganisms cannot possibly consume a very significant portion of the soluble BOD during the six hours in which it would pass through the system. Indeed, it may take several days under very similar conditions to consume the 100 mg/*L* in a BOD bottle. There is no reason to believe that the reaction will take place any faster inside the aeration basin. Therefore, constantly feeding the system a fresh supply of wastewater containing 100 mg/*L* soluble BOD provides no real advantage.

Additionally, since the bacteria are dispersed, 10 MGD of water containing whatever concentration of microorganisms that exist in the system would be flushed over the effluent weir of the secondary clarifier. This loss must be made up for by the rate of growth of the bacterial population. The six hour residence time could be at or below the minimum mean cell residence time required for growth; therefore, washout of any bacterial growth will occur. In any case, it would put the microorganisms to an extreme handicap in establishing themselves.

In this start-up procedure, the influent flow is shut off. The water within the plant is then recirculated between the secondary clarifiers and the aeration basins. With this method, the mean cell residence time may be made as long as necessary simply be retaining the entire mass of microorganisms within the system. The bacteria proceed to consume the soluble BOD present and subsequently increase in concentration, rapidly lowering the F/M value. Eventually, the energy level drops to a point where the bacteria begin to flocculate and the amount of food remaining becomes a limiting factor in further growth.

Now is the time to introduce more food to the microorganism population. Again, it might be disadvantageous to feed the full 10 MGD flow through the system for the same reasons stated previously. The flow instead is introduced at a gradually increasing rate, thus gradually accelerating the rate of introduction of available food to match the growing concentration of microorganisms. In terms of the food-to-microorganism ratio, "F" might be matched to an ever increasing "M" in a way to maintain a value of F/M that would neither inhibit the growth rate nor disperse the bacteria. As an additional advantage, a reduced rate of feed would produce a lower overflow rate in the secondary clarifiers, making them more efficient than normally possible. This fact could be used as justification for allowing higher than normal F/M values during the low flow portions of the start-up.

The value of F/M could ideally be held constant or gradually decreased by carefully regulating the flow rate through the plant. Practically, however, this is not possible due to uncertainties in the actual soluble BOD concentration in the waste stream and also because the flows cannot usually be regulated with any precision. Much more feasible from an operating standpoint would be to keep the value of F/M within a range that would eventually narrow down to the optimum when the system is started. The feed could be increased in a periodic step-wise manner as long as the period steps did not cause the F/M to exceed a "safe" level.

Although bacteria are the primary motivators in stabilizing the organic wastes, other types of microorganisms play an important role in an activated sludge system. More complex single cell organisms called protozoa act as scavengers devouring dispersed bacteria producing a highly clarified effluent. These protozoa also serve as useful indicators of the overall condition of the system. Because of their greater complexity and size, they are more sensitive to changes in their environment and can be more easily observed under a typical compound microscope.

The usefulness of microscopic indicators in this type of start-up scheme is obvious. Following each periodic (step) increase in feed to the system, the value of F/M will rapidly pass from a high level to one near the normal optimum. Timing the next periodic (step) increase is critical both to the viability of the microbial population and to the overall start-up time requirements. The F/M value may be guessed at based on measured MLVSS and either estimated BOD loads or rapid tests that approximate BOD such as COD to TOC analysis. These lab tests are very important during start-up; however, only by microscopic inspection can the system's energy level be immediately and directly confirmed. In addition, this observation may detect nutrient deficiency, low pH, low dissolved oxygen levels and other problems hindering most start-ups. The discovery by microscope of one of these defects is independent of plant instruments that may be as yet inaccurately calibrated or laboratory tests with which the technician is unfamiliar.

Besides producing a rapid and controlled growth of active microorganisms, the periodic (step)-feed procedure has several other virtues. Using this procedure, a full, active population may be grown from even the smallest amount of seed organisms. A bucket of activated sludge from another plant will contain all the types of microorganisms necessary to start a system and may be used if it is uncertain that they exist normally in the mill wastewater. This small population of microorganisms, when introduced during the zero-flow step, will proliferate and stabilize the F/M value within a matter of several days.

The periodic (step)-feed method minimizes the possibility of sudden kills of the active bacteria mass. The microbial population is extremely fragile during the early stages of its development, but it is also during this time that most of the wastewater flow bypasses the system. This effect reduces the possibility that a slug of toxic, inhibitory or high strength organic material in the waste stream could fill the system to a concentration that would endanger its growth.

Finally, there is no period of "population stabilization" after the target MLVSS level is attained using the periodic (step)-feed method. Often in the start-up of an activated sludge system by other methods, the types of microorganizms present in the system when the target is reached are not the same ones that will predominate during the normal operation. This is because the population produced by using these methods develops under conditions, such as the energy level, that are far removed from those prevalent after the target is reached. A considerable length of time may be required for a turn-over of the types of microorganisms represented in the population. Plant performance can be expected to be somewhat less than optimum during this period. By gradually "zeroing in" on the optimum F/M value, the periodic (step)-feed technique cultivates a highly diverse population of microorganisms which are more adequately suited for survival during normal operation.

2.556 Operating of a Municipal Plant Receiving Paper Mill Wastewater

by Anthony A. Leotta and W.A. Hopsecger

Operating experience described in this section were obtained from a treatment plant with present day domestic flows averaging from 2.0 to 2.5 MGD (7,570 to 9,460 cu m/day) and paper mill flows from 0.3 to 0.5 MGD (1,135 to 1,890 cu m/day). Paper mill wastewater averages 600 mg/*L* suspended solids and 250 mg/*L* BOD. Domestic wastewater is relatively weak and averages 75 mg/*L* suspended solids and 50 mg/*L* BOD.

Nutrient deficiencies are experienced at this plant. Urea is introduced into the aeration tanks to provide a concentration of 5 mg/*L* at the head of the aeration tank. Another satisfactory approach to solving the nitrogen deficiency is to bypass a portion (10 to 20 percent) of the primary influent directly to the aeration tanks. Nutrients which are usually removed by primary treatment are diverted to the aeration tanks to satisfy the nitrogen deficiency.

Mixed liquor suspended solids are adjusted to 2,500 mg/*L*. Experience seems to indicate that paper waste is difficult to consume by microorganisms and therefore may require more microorganisms than in most domestic treatment plants to do the job.

DO levels in the aeration tank are maintained between 2 and 3 mg/*L* throughout the entire tank. Too much air (over 3 mg/*L*) results in a breaking up of the floc and a resultant decrease in settleability. Too little air results in a loss of beneficial activated sludge bacteria and could result in an undesirable explosion of filamentous growths.

Optimum return activated sludge (RAS) flows range from 40 to 50 percent, depending on flow and secondary clarifier conditions. Return rates of 20 to 25 percent do not maintain the proper MLSS in aeration. Rates in excess of 50 percent cause an increase in overflow rates which result in bulking sludge flowing over the clarifier weirs.

Depending upon the type of solids in the return sludge, the wasting schedule is reduced during the autumn and winter season in order to maintain higher MLSS in aeration. Since microorganisms become less active (sluggish) in colder temperatures, MLSS are raised to about 3,000 mg/*L* during the colder seasons. Closer control of MLSS vs. suspended solids in return sludge is required during the colder season. Experience has shown that the ratio between MLSS and return sludge suspended solids should be about 3. In other words, with the best range of MLSS from 2,000 to 3,000 mg/*L*, suspended solids in the return sludge should be maintained between 6,000 to 9,000 mg/*L*. Wasting schedules are calculated to maintain this ratio.

The operating guidelines are summarized as follows:

1. F/M ratio <1.0
2. SVI around 200
3. MLSS of 2,500 mg/*L* (warm weather)
4. MLVSS, 70 percent of MLSS
5. DO, 2 to 3 mg/*L* throughout aeration tank
6. Return activated sludge rate, 40 to 50 percent
7. Return activated sludge suspended solids, 7,500 mg/*L*
8. MLSS/RAS SS, 3

2.557 Acknowledgments

Authors in this section on how to treat pulp and paper mill wastes included James J. McKeown, W.A. Eberhardt, R.S. Dorr, Anthony A. Leotta and W.A. Hopsecger. Reviewers of this section included Al Brosig, Anthony A. Leotta, Larry Metzger, David B. Buckley, Ray Pepin and W.A. Eberhardt.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

2.55A Why must accurate records be kept?

2.55B Why should the effluent from a pulp and paper mill activated sludge process contain around 0.5 mg/*L* ammonia nitrogen and 0.25 mg/*L* phosphorus?

2.55C Under what conditions might the paper industry shut down an activated sludge process?

2.55D Why is the periodic feeding (step-feed) technique for process start-up of activated sludge systems effective?

2.56 **Brewery Wastewaters** by Clifford J. Bruell

2.560 Operational Safety

In brewery wastewater treatment plants, as in other food or industrial treatment plants, there exists the potential of tremendous fluctuations within influent wastewater characteristics. This is especially true with respect to the organic content of the influent. A brewery wastewater treatment plant that receives an organic load of 25,000 pounds (11,000 kg) of BOD on one day may experience an organic loading of 50,000 pounds (22,000 kg) of BOD (or more) the following day. Economically it is impossible to design, construct and operate a wastewater treatment plant that will as a matter of routine, treat highly fluctuating loads or the entire potential load from an industrial plant. Therefore, a multifaceted waste load monitoring program to *CONTROL* the source of the wastewaters and to *CAPTURE FOR REUSE* valuable raw materials is essential.

Due to the nature of brewery operations and the characteristics of brewery wastewater, *MOST BREWERY WASTEWATER TREATMENT PLANTS ARE SMALL WASTEWATER TREATMENT PLANTS THAT DO THE WORK OF LARGE WASTEWATER TREATMENT PLANTS.* Therefore, a tight, well organized operation is imperative in order to meet NPDES permit goals. The various operational strategies described in this section are examples of what has worked best at a typical plant. These methods are *NOT THE ONLY WAY* to get the job done. Careful experimentation (where only one variable at a time is changed) is necessary to determine the best operating methods at every individual treatment plant. There is no substitute for experience and every operator has experience. The key to successful operation is using existing experience and to build on that foundation with new, well documented experience.

2.561 Sources of Characteristics of Brewery Wastewater

SOURCES OF BREWERY WASTEWATER

In the brewing industry, as in other food processing industries, there is always some minimal loss of raw materials. Brewing ingredients such as malted barley, rice, starch, hops and yeast often become part of the wastewater. Raw material losses can be controlled by the use of capture systems and recycle loops; however, it is inevitable that some portion of this material will become waste. The malting of barley requires large volumes of water which flushes from the grain concentrated organic materials throughout the malting process. To maintain sanitary conditions within a food plant, large volumes of cleaning solutions are required. These soapy solutions, that often have a high pH (caustic soda) and their associated rinse water, also become part of the brewery wastewater stream. A small portion of the product, *BEER* and brewery by-products (brewers yeast) are very concentrated (organically), and can enter the waste stream. On occasion, lubricating oils or other maintenance or utility materials (ammonia, glycol coolant, acids) may accidentally enter the sewer line. Together these items are the sources of brewery wastewater.

CHARACTERISTICS OF BREWERY WASTEWATER

Brewery wastewater that contains starches, sugars and alcohol can be characterized as organically strong. This means that the wastewater may often exert a BOD of 1,200 mg/*L* or greater (municipal wastewater often has a BOD of 200 mg/*L*). Much of this BOD is "soluble" or "dissolved" and only 10 to 15 percent of this BOD can be removed by primary clarification. Therefore, a highly efficient secondary treatment process, such as activated sludge, is necessary to successfully treat brewery waste. Nutrients such as nitrogen and phosphorus are often considered to be deficient within brewery wastewater. Textbook data often states that the ratio of BOD:Nitrogen:Phosphorus that is necessary to produce desirable activated sludge microorganisms is 100 pounds BOD: 5 pounds N: 1 pound P, within the influent to the aeration basins. If wastewater has a very high BOD, due to starches and sugars, then the nitrogen and phosphorus levels considered *NORMAL* in municipal wastewater would be deficient when compared to the BOD in brewery wastewater. If cleaning solutions (acids and caustics) are released rapidly to a brewery wastewater treatment plant (instead of being slowly metered), drastic pH fluctuations within the influent will result. This pH fluctuation (pH 4 to 10) can cause operational problems if the influent is not neutralized.

2.562 Brewery Wastewater Treatment Plant Tour

OVERALL PICTURE

A typical brewery wastewater treatment plant flow layout is shown on Figure 2.15. Typical data has been included to give you the "feel" of the relative operating conditions of this plant. To provide you with an overall picture of the plant, let's take a *WALKING TOUR* of the plant shown on Figure 2.15. At each location try to picture the equipment that would be seen and the process that is taking place. *USE YOUR EXISTING KNOWLEDGE OF WASTEWATER TREATMENT AND TRY TO RELATE IT TO THIS BREWERY WASTEWATER TREATMENT PROCESS.* Also, much of the other information within the remainder of this section on brewery wastewater treatment will be somewhat specific to the typical brewery wastewater treatment plant described.

PRETREATMENT OF WASTEWATER

To begin the tour let us start at the headworks of the plant. At this point the flow from various portions of the brewery, which is collected by a massive network of piping, valves, floor drains and sumps, is delivered to the wastewater treatment plant via a lift station and several gravity lines. An influent flow of 3.0 MGD (11,350 cu m/day) containing 1,200 mg/*L* BOD (30,000 lbs or 13,600 kg/day) and 250 mg/*L* SS (6,000 lbs or 2,700 kg/day) would be an average loading to this plant. The first step of the treatment process is bar screening. At this brewery the automatically raked bar screen removes can lids, cans, glass, pieces of wood, rags and balls of "grain and keg wax" that form within the sewer lines. Immediately following the bar screening step is the *GRIT REMOVAL CHAMBER* or grit channel. Grit at a brewery wastewater treatment plant consists of malted barley and hops. Depending on what raw materials are used, grains such as corn grits or rice might also be captured within a grit chamber. These brewing materials are readily settled and removed from the waste stream. Therefore, this grit material has some limited reuse value, an example of this would be as a compost mix additive. Estimation of the volumes of grit that are generated at various breweries is very difficult because these volumes would depend on whether malting was being done on site and the efficiency of the recapture systems. At this brewery between 0.5 to 1.0 cubic yards of grit per MG (0.1 to 0.2 *L*/cu m) of flow is generated.

A useful operational aid within the area of the bar screen is an in-line continuous monitoring pH meter. A meter at this location, with a low and high pH alarm, can alert an operator of *POTENTIAL pH PROBLEMS* long before they *BECOME PROBLEMS.* The magnitude of a pH fluctuation and the duration can alert an operator of the severity of the problem. An automatic/manual acid addition system is used to meter (pump) concentrated H_2SO_4 to neutralize caustic cleaning solutions. An additional recording pH meter is used to control/monitor the acid addition. At this brewery the acid addition step is done within the grit chamber area; however, a more desirable addition and monitoring point would be downstream of the surge tank or primary clarifier. Other brewers have successfully used automatic caustic addition systems (50 percent NaOH via pump) to neutralize acid spills. If an automatic caustic addition system is not present, stores of caustic materials such as lime or NaOH should be kept on hand for emergency situations (large acid spills).

After grit removal the influent wastewater stream enters a 0.5 MG (2,100 cu m) surge tank. Brewer production is often a batch process. A good example of this is the malting process. When a malting tank is drained of liquid within the "steeping out" process, this can exert an immediate high hydraulic load (8 MGD (30,000 cu m/day) flow rate) upon the wastewater treatment plant. The surge tank is used to catch this peak hydraulic load and then the waste can be metered to the plant at a controlled rate. Pumping from the surge tank at a controlled rate of flow eliminates shock loadings to the aeration basins and prevents disturbing the sludge blanket within all of the plant clarifiers. Another function of the surge tank is dilution of high strength organic wastes within the influent. Beer has a very high BOD that can exceed 200,000 mg/*L*. If an accidental beer spill occurred, consisting of 10 to 100 Bbls of beer (31 gallons/Bbl), this would be considered a major overload situation. A load of this magnitude, unchecked, could cause a plant process failure. However, when a surge tank is used, dilution will occur within the tank and the entire waste load is *METERED* into the aeration system. When the waste material then enters the aeration system at a slightly elevated organic concentration (rather than greatly elevated), it is possible to meet dissolved oxygen requirements and to form a desirable biomass. To facilitate mixing and dilution several floating aerators are used. These units rise and fall (float) just as the tank level does. These mixers achieve a small degree of preaeration. Oils and grease, within the waste stream, are also "conditioned" by the mixing action of the surge tank. These

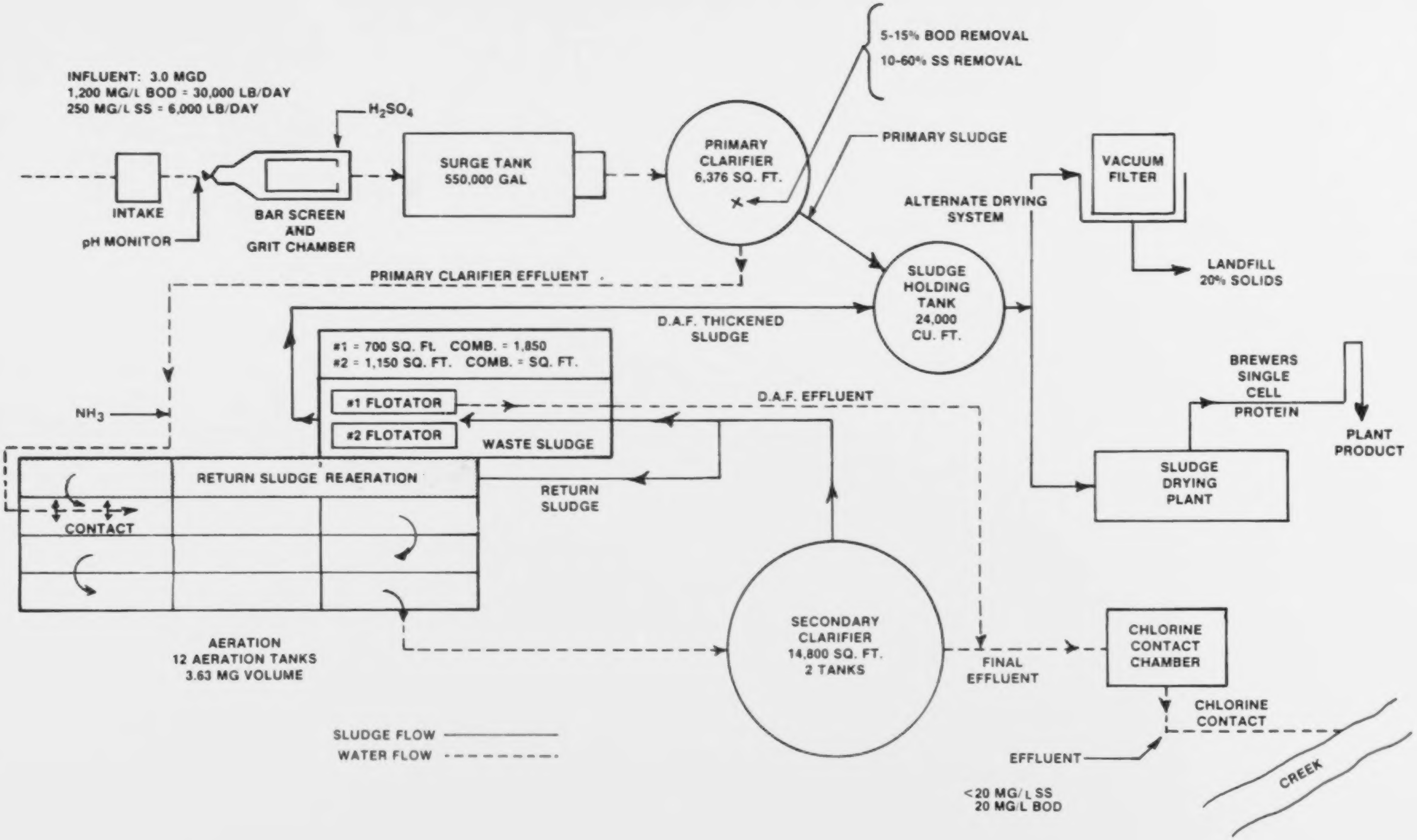
INFLUENT: 3.0 MGD
1,200 MG/L BOD = 30,000 LB/DAY
250 MG/L SS = 6,000 LB/DAY
H2SO4
INTAKE
pH MONITOR
BAR SCREEN AND GRIT CHAMBER
SURGE TANK 550,000 GAL
PRIMARY CLARIFIER 6,376 SQ. FT.
5-15% BOD REMOVAL
10-60% SS REMOVAL
PRIMARY SLUDGE
VACUUM FILTER
ALTERNATE DRYING SYSTEM
LANDFILL 20% SOLIDS
PRIMARY CLARIFIER EFFLUENT
SLUDGE HOLDING TANK 24,000 CU. FT.
D.A.F. THICKENED SLUDGE
#1 = 700 SQ. Ft. COMB. = 1,850
#2 = 1,150 SQ. FT. COMB. = SQ. FT.
#1 FLOTATOR
#2 FLOTATOR
WASTE SLUDGE
D.A.F. EFFLUENT
BREWERS SINGLE CELL PROTEIN
PLANT PRODUCT
NH3
RETURN SLUDGE REAERATION
CONTACT
RETURN SLUDGE
SLUDGE DRYING PLANT
AERATION
12 AERATION TANKS
3.63 MG VOLUME
SECONDARY CLARIFIER 14,800 SQ. FT. 2 TANKS
FINAL EFFLUENT
CHLORINE CONTACT CHAMBER
CHLORINE CONTACT
EFFLUENT
<20 MG/L SS
20 MG/L BOD
CREEK
SLUDGE FLOW
WATER FLOW

Fig. 2.15 *Flow schematic of brewery wastewater treatment plant*

materials become slightly coagulated which results in an increased removal efficiency of floating oil and grease (F.O.G.) within the primary clarifier.

The control of the surge tank level is a manual operation controlled by the operator (level alarms and overflow provisions are present). Periodically the operator checks the surge tank level and adjusts the rate of waste pumping to maintain a desired level. From the surge tank the waste is pumped into the primary clarifier.

PRIMARY CLARIFIER

The primary clarification step typically removes 10 to 60 percent of the influent suspended solids. However, because brewery waste has a highly soluble organic content, a smaller amount of BOD removal is achieved at this point. A 5 to 15 percent BOD removal is typically obtained; this fact also indicates that only a small amount of BOD is associated with the solids removed here. Though oil and grease are not a major portion of the influent stream, some is skimmed from the primary clarifier surface along with small amounts of yeast, hops and grain hulls that tend to float within the primary clarifier. Sludge solids concentrations of materials removed from the primary clarifier typically range from 3 to 5 percent solids. Sludge blanket depths are measured periodically. Sludge pumping frequency and the rate of removal (pumping rate) are adjusted to maintain a minimum sludge blanket depth within the clarifier without causing "coning."

2.563 Nutrient Addition

Brewery wastewater is usually nutrient deficient. Most brewery wastewaters have a deficiency in both nitrogen and phosphorus. To supplement nitrogen, ammonia gas (or liquid) can be metered into the primary clarifier effluent. Some brewery wastewater treatment plants use phosphoric acid, H_3PO_4, as an additional source of phosphorus. At the brewery wastewater treatment plant under examination here, adequate quantities of phosphorus are present within the influent. This is due to the fact that phosphorus is derived from both malting byproducts and phosphorus based cleaning solutions. However, within this plant, nitrogen is deficient.

A desirable organic strength to nutrient ratio is 100 pounds BOD: 5 pounds N: 1 pound P. In order to calculate the quantities of nutrient addition required it is first necessary to have some estimate of organic strength of the waste. To run a 5-day BOD test as an estimate of organic strength is impractical because it takes too long! This is especially true if nutrient addition rates have to be adjusted on a *DAILY* basis. Therefore, analysis such as chemical oxygen demand (COD) or total organic carbon (TOC) is necessary to provide relatively quick results. These tests can be run within several hours and a BOD value can be calculated once a BOD:COD or BOD:TOC ratio has been established. As an indication of the amount of nitrogen that is already present within the influent, NH_3-N analysis is performed on a 24-hour composite sample of the primary clarifier effluent. This same sample is used for other analyses such as TOC analysis. As an estimate of nitrogen content, NH_3-N analysis is used because it is easier to run than T.K.N. (Total Kjeldal Nitrogen) analysis. This usually ends up in a shift in the BOD:N ratio *FROM 100* pounds BOD:5 pounds N (T.K.N.) *TO 100* pounds BOD:2 pounds NH_3-N. (This is true because in this wastewater the ratio of 5 pounds T.K.N.:2 pounds NH_3-N holds true.) The same philosophy applies to phosphorus analysis (it is easier to run ortho-P analysis than total-P analysis).

An example of NH_3-N addition calculation sheet is provided (see the sample calculation). The basic principles of the addition procedure is to

1. Estimate the organic strength of the waste (via a quick method such as TOC).
2. Estimate the amount of nutrient already present (via a quick method such as NH_3-N).
3. Estimate the supplemental amount of nutrient required.

The sample calculation procedure is designed to allow addition of the nutrient on a continuous basis for 24 hours. Also, when the plant effluent analysis reveals 1.0 mg/*L* or greater residual of the nutrient that is being supplemented, this is an indication that the addition quantity is sufficient. If the residual is far above or below the 1.0 mg/*L* concentration, the addition ratio should be adjusted accordingly.

NUTRIENT ADDITION SAMPLE CALCULATION

Sample Data:

Item	Data
Primary Effluent, 24-hour Composite Total Organic Carbon (TOC)	554 mg/*L*
BOD:TOC Ratio	2.2:1
Calculated Sample BOD 2.2 × 554 mg/*L*	1,219 mg/*L*
Estimated Flow for the Next 24 hours	3.3 MGD
Final Effluent, 24-hour Composite NH_3-N Concentration	0.88 mg/*L*
Primary Effluent, 24-hour Composite NH_3-N Concentration	8.36 mg/*L*

SAMPLE AMMONIA ADDITION CALCULATIONS

1. Estimate the present day's BOD loading in pounds of BOD per day.

$$\begin{aligned}\text{BOD Loading, lbs/day} &= \text{Flow, MGD} \times \text{Est. BOD, mg/}L \times 8.34\ \text{lbs/gal}\\ &= 3.3\ \text{MGD} \times 1{,}219\ \text{mg/}L \times 8.34\ \text{lbs/gal}\\ &= 33{,}549\ \text{lbs BOD/day}\end{aligned}$$

2. Calculate the amount of ammonia (NH_3-N) required in pounds per day. Assume an ammonia requirement of 2 pounds NH_3 per 100 pounds BOD.

$$\begin{aligned}NH_3\ \text{Required, lbs/day} &= \text{BOD, lbs/day} \times \frac{NH_3\text{-N, lbs}}{\text{BOD, lbs}}\\ &= 33{,}549\ \frac{\text{lbs BOD}}{\text{day}} \times \frac{2\ \text{lbs}\ NH_3\text{-N}}{100\ \text{lbs BOD}}\\ &= 671\ \text{lbs}\ NH_3\text{-N/day}\end{aligned}$$

3. Estimate the ammonia (NH_3-N) supplied to the aeration basins in the primary clarifier effluent.

$$\begin{aligned}NH_3\ \text{Supplied, lbs/day} &= \text{Flow, MGD} \times NH_3\text{-N, mg/}L \times 8.34\ \text{lbs/gal}\\ &= 3.3\ \text{MGD} \times 8.36\ \text{mg/}L \times 8.34\ \text{lbs/gal}\\ &= 230\ \text{lbs}\ NH_3\text{-N/day}\end{aligned}$$

4. Determine the amount of ammonia (NH_3-N) that must be added to the primary effluent.

$$\begin{aligned}NH_3\ \text{Added, lbs/day} &= NH_3\ \text{Required, lbs/day} - NH_3\ \text{Supplied, lbs/day}\\ &= 671\ \text{lbs/day} - 230\ \text{lbs/day}\\ &= 441\ \text{lbs}\ NH_3\text{-N/day}\end{aligned}$$

NOTE: Effluent NH_3-N concentration is 0.88 mg/*L* which is a satisfactory (possibly a little high) level.

5. Calculate the rotameter setting. The rotameter constant is 5.45 lbs NH_3-N for a 24-hour period for each one percent.

$$\text{Rotameter Setting, \%} = \frac{NH_3\text{-N Added, lbs/day}}{5.45\ \text{lbs}\ NH_3\text{-N/day/\%}}$$

$$= \frac{441\ \text{lbs}\ NH_3\text{-N/day}}{5.45\ \text{lbs}\ NH_3\text{-N/day/\%}}$$

$$= 81\%$$

2.564 Aeration Basic Flow Scheme

Immediately after nutrient addition, the primary clarifier effluent enters the first aeration basin or "contact cell." The wastewater is highly bio-oxidizable and combined with the return sludge (which has been re-aerated) they exert an immediate high oxygen demand upon the aeration system. Figure 2.16, the Simplified Aeration Basic Flow Schematic, is a clear overview of the activated sludge system. The fresh waste is distributed throughout the basin and mixed with return sludge from the adjacent "Return Sludge Reaeration" cell. Together, the return sludge and fresh waste travel in a "plug flow" pattern through nine (9) aeration cells (0.303 MG or 1,150 cu m each) in a serpentine fashion. Assuming an average flow of 3.0 to 3.5 MGD (11,350 to 13,250 cu m/day) and a 35 percent return sludge pumping rate, aeration time is approximately 14 to 16 hours. The mixed liquor leaving the final aeration cell is split and distributed to the two secondary clarifiers. The activated sludge mixed liquor is next separated from the final effluent within the secondary clarifier. The sludge organisms settle within the quiescent (calm) clarifier and are removed from the bottom of the tank while the clear effluent overflows the tank weirs. From the secondary clarifier the secondary effluent passes through a chlorine contact chamber and is chlorinated. If necessary the final effluent is dechlorinated with sodium bisulfide before discharge to the receiving waters. A small portion of the return sludge is continuously wasted. Return sludge that is not wasted enters the return sludge re-aeration basins. Flow of the return sludge within the re-aeration system is also in a "plug flow" pattern. Return sludge within the re-aeration phase is allowed to "rest" for 18 to 20 hours before re-entering the contact cell of the aeration system. The trip of a sludge particle that makes the complete loop from the contact cell, through the entire aeration and re-aeration system and back to the contact cell, could take 32 to 36 hours under the previously described operating conditions.

2.565 Activated Sludge System Operation

Brewery wastewaters, as well as many other food processing wastewaters, are highly bio-oxidizable. This means that when activated sludge organisms come in contact with the fresh wastewater, the organisms will immediately start to use the wastewater as a food source. When this happens there is a sudden demand for oxygen by the sludge organisms. Dissolved oxygen (DO) uptake rates in excess of 200 mg O_2/hr/*L* may occur. The aeration basin DO levels might even drop to 0.5 mg/*L* or less. Some believe that when DO levels greater than 5.0 mg/*L* are *NOT* maintained, this will promote the growth of filamentous organisms. This is just one possible cause of filamentous growth. Filamentous organisms are often cited as a possible cause of sludge "bulking." To avoid DO level sags within the first aeration basin or "contact cell," and the associated possibility of sludge "bulking," several design modifications have been made to the basin.

The Contact Cell Aeration Mode is shown within Figure 2.17. This is an enlarged view of the first aeration basin that receives the primary effluent. The view shown here represents what would be seen if you were looking down into a nearly empty aeration basin. A jet-type aeration system that uses Venturi nozzles is the type of aeration system used. Two large submerged basin recirculation pumps collect mixed liquor and pump it into the "liquid" header. Air or oxygen is metered into the "gas" header. When the "liquid" and "gas" pass through the aeration Venturi nozzles simultaneously, a jet action occurs and the gas becomes impinged within the liquid. These aeration basins are not covered. This type of jet aeration system is used within all aeration basins and the capability of using air *OR* oxygen within all of the "gas" headers exists. In most basins where DO requirements can be met with air, standard aeration blowers are used to supply air and satisfy oxygen demands. However, in the contact cell where DO demands are high, oxygen is necessary (pure oxygen is more effective than air because air is only 21 percent O_2). The oxygen is first vaporized from liquid and then metered into the "gas" header within the contact cell. When oxygen is used within the header, *NO AIR* is used simultaneously. Within the "contact cell" special modifications direct the raw primary clarifier effluent and the return activated sludge from the last reaeration basin to within the immediate vicinity of the submerged pump's suction. This is accomplished by piping and duct work that are equipped with flow metering devices. This modification enables the fresh re-aerated return sludge and wastewater to be mixed and quickly distributed throughout the contact cell. With the aid of oxygen, it is possible to maintain minimum DO levels. An on-line DO meter and lab meter are used to monitor the basin and frequent oxygen flow rate adjustments are made. Following "contact" the mixed liquor moves to the aeration basin on the right (in a plug flow fashion) through a submerged flow control gate. The "plug flow" mode of aeration basin flow is used because this type of basin flow (rather than "complete mix") has also been cited as being instrumental in the *PREVENTION* of the growth of filamentous organisms or dispersed growth. Also, this particular aeration scheme has been the most successful mode at this plant for obtaining the required 20/20 BOD/SS effluent.[15]

Aeration basin MLSS levels are run at various levels between 2,000 to 2,800 mg/*L* (85 percent VSS). Many factors dictate the exact MLSS level that is maintained. An example of this is influent organic loading. When very low ogranic loadings occur to the aeration basins, a relatively low MLSS should be maintained to prevent an excessive sludge age from developing. The inverse relationship is also true to a certain degree. Temperature is another factor that greatly influences the MLSS level that should be maintained. The activity (ability to remove carbon) of the sludge organisms within the biomass is highly temperature dependent. An increase in basin temperature of only 10°C (i.e. an increase from 20°C to 30°C) can *DOUBLE* the activity of the biomass. Therefore, during periods of higher summer temperatures, a lighter biomass MLSS can achieve the same organic removals as twice (2×) the biomass under winter operating conditions (temperatures). As the sludge organisms increase their activity as a result of warmer basin temperatures, they also increase the quantities of oxygen required. This means that at high MLSS levels and high basin temperatures, it is often difficult to maintain satisfactory DO levels within the aeration basins. When this happens and aeration capabilities cannot be increased, it often becomes necessary to trim back the MLSS levels until minimum DO levels are achieved again.

The suspended solids levels maintained within the return sludge re-aeration basins often range from 6,000 to 10,000 mg/*L*. This concentration depends on the settling characteris-

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[15] *An effluent with less than 20 mg/L of both BOD and suspended solids.*

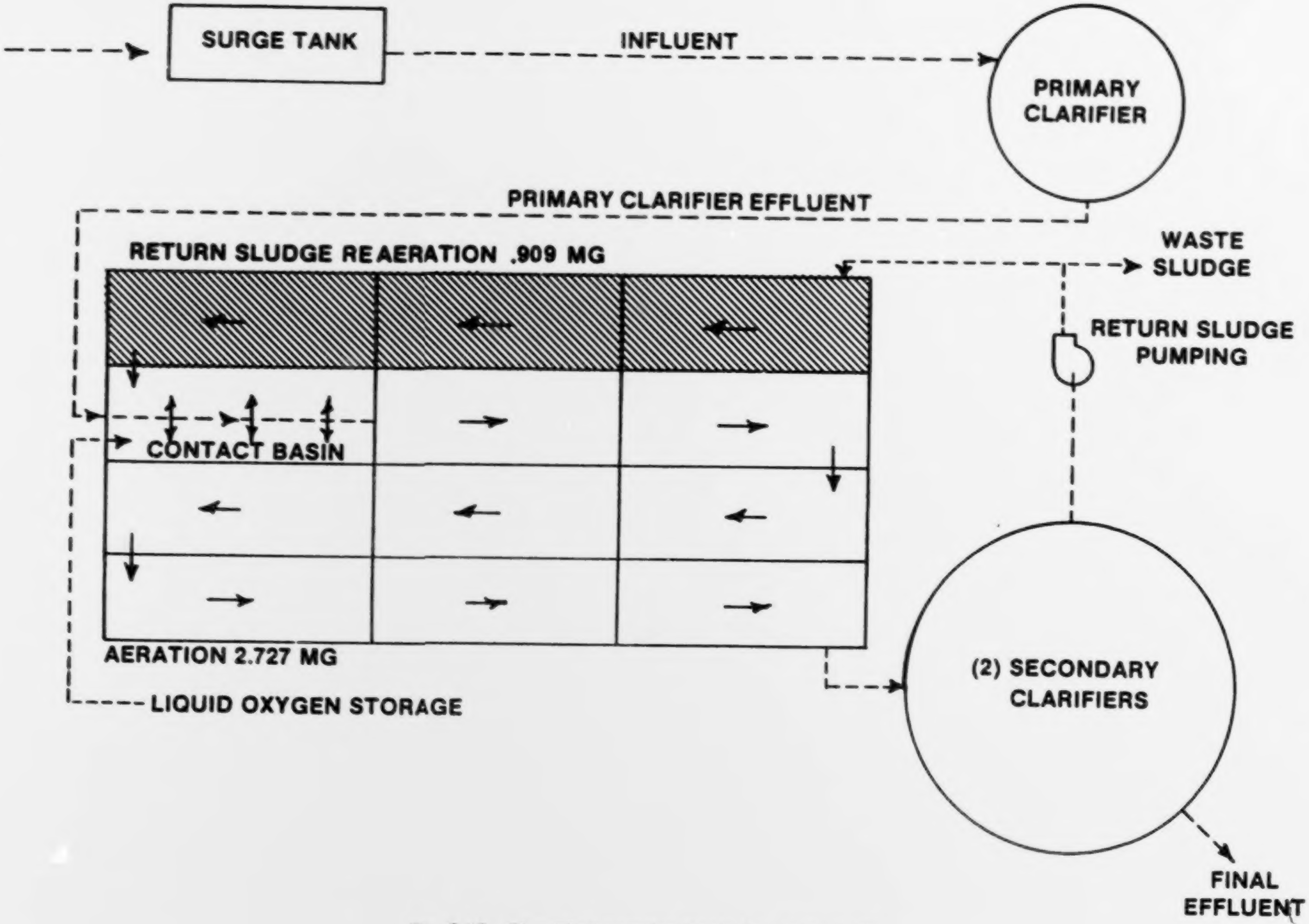

SURGE TANK
INFLUENT
PRIMARY CLARIFIER
PRIMARY CLARIFIER EFFLUENT
RETURN SLUDGE REAERATION .909 MG
WASTE SLUDGE
RETURN SLUDGE PUMPING
CONTACT BASIN
AERATION 2.727 MG
LIQUID OXYGEN STORAGE
(2) SECONDARY CLARIFIERS
FINAL EFFLUENT

Fig. 2.16 Simplified aeration basin flow schematic

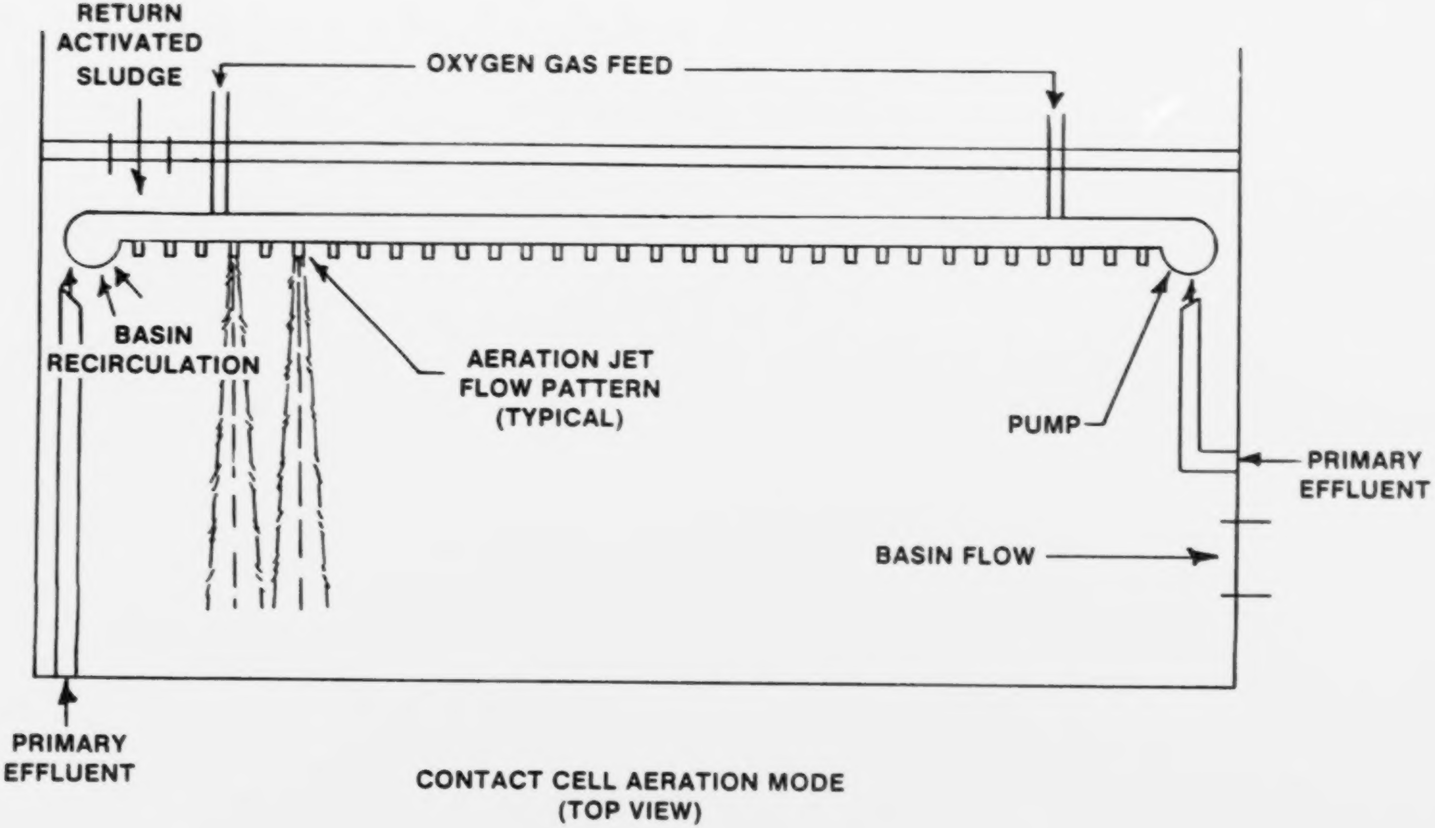

RETURN ACTIVATED SLUDGE
OXYGEN GAS FEED
BASIN RECIRCULATION
AERATION JET FLOW PATTERN (TYPICAL)
PUMP
PRIMARY EFFLUENT
BASIN FLOW
PRIMARY EFFLUENT
CONTACT CELL AERATION MODE (TOP VIEW)

Fig. 2.17 Contact cell aeration mode (top view)

tics of the sludge and the operation of the secondary clarifiers. Return sludge rates are adjusted to maintain a sludge blanket between 12 to 18 inches deep (30 to 45 cm) within the secondary clarifier. Numerous blanket depth measurements (with a "thief" type sampler) are made to control the blanket depth. The goal is *NOT* to build a *DEEP* blanket (that leaves sludge within the clarifiers for a long period of time) *OR* to pump the blanket levels *TOO LOW* and then pump only dilute sludge into the return sludge re-aeration basins. An on-line suspended solids meter is used to monitor return sludge suspended solids levels and to aid with this determination. Also, grab samples of the secondary clarifier influent are taken frequently to measure sludge settling rates and sludge volume indices (SVIs). Once again, just as the relationship between temperature and basin DO levels dictates maximum MLSS levels, the settling characteristics of the sludge within the secondary clarifier may also dictate the maximum MLSS level that can be maintained under aeration. To control clarifier sludge blanket depth, return sludge pumping rates can be increased only to a certain point (about 50 percent), and after that further increases in return rates are not beneficial. This is because the additional return that is pumped back through the re-aeration and aeration system ultimately comes back into the clarifier and causes a high hydraulic loading. This increased hydraulic loading into the clarifier can cause the characteristically light fluffy sludge to become stirred up and possibly bulk. If the sludge settling characteristics are poor (high SVI) and increasing return sludge pumping rates do not control sludge blanket depths, again MLSS levels must be trimmed back.

Other commonly used activated sludge operational control factors such as the food to microorganisms ratio (F/M), mean cell residence time (MCRT) and sludge age, are very difficult to us as the *SOLE* determining factor to direct sludge wasting on a day to day basis. These factors can be very useful as plant design figures or they can be used to determine desirable operating ranges. However, to calculate these factors and adjust sludge wasting rates or to attempt to adjust MLSS levels on a daily basis "shooting" at a specific *F/M SET POINT* becomes impossible. When highly fluctuating organic loads enter a plant it is very difficult to waste or build MLSS rapidly enough (within 24 hours) to meet a specific set point. Instead, select a proper *MLSS* level *SET POINT* which actually results in an F/M, MCRT or sludge age value that floats in the vicinity of what would approximate a desirable "factor" range! In reality there are many interrelated and independent factors that influence plant operation. These factors include basin DO levels that can be maintained, sludge settling characteristics, effluent quality and many other factors dictate what MLSS level can be maintained. This proper MLSS level must be determined experimentally by *SLOWLY* adjusting the MLSS level together with careful observation of plant behavior. Ultimately a proper MLSS *SET POINT* can be determined and used to control sludge wasting activities. However, you must realize that this "proper MLSS set point" may have to be adjusted when influent characteristics change and when seasonal changes occur.

As previously described, all sludge that is not wasted flows into the re-aeration portion of the plant. There are numerous benefits from return sludge re-aeration. A list of some of the advantages is as follows:

1. Basic math indicates that if nine aeration basins are maintained at a MLSS of 2,000 mg/*L*, then the addition of only three return sludge re-aeration basins (*ALL* basins equal 0.303 MG or 1,150 cu m) at a SS level of 6,000 mg/*L* (return sludge concentration) will *DOUBLE* the available biomass within the activated sludge system. (9 aeration × 2,000 mg/*L* = 3 re-aeration × 6,000 mg/*L* or double initial capacity.)
2. During periods of high organic loading, the re-aeration phase allows adequate "rest" time for the sludge organisms to metabolize **ad**sorbed and **ab**sorbed BOD.
3. If a poison or toxic substance should enter the plant (heavy metals, pH or temperature shift) only a small portion of the biomass will be destroyed. The plant can recover quickly and be back on line within a short period of time (again achieving satisfactory BOD removal).
4. The "rest" period within re-aeration seems to condition the sludge so that it will readily accept new influent loading and consistently obtain high BOD removals (+98 percent).

2.566 Sludge Wasting

An example of a sludge wasting calculation is included. The major basis of the calculation is that sludge wasting will be done continuously for a 24-hour period with the *GOAL* being a desired *MLSS "SET POINT."* Every 24 hours all of the data is reviewed and a new sludge wasting rate is implemented.

The following illustrates the wasting formula calculation. As a quick indication of influent organic strength, a total organic carbon (TOC) measurement is used to project BOD loading.

SAMPLE DATA:

Item	Data
Final Aeration Cell MLSS	2,420 mg/*L*
Primary Effluent, 24-hour Composite Sample, TOC	554 mg/*L*
Desired MLSS set point	2,200 mg/*L*
Return Sludge (waste) SS	7,160 mg/*L*
Estimated Flow for the Next 24 hours	3.3 MGD

Volumes and Assumptions

1. Volume of each aeration cell 0.3 MG.
2. Nine aeration cells, total aeration volume 2.7 MG.
3. Solids in secondary clarifiers are equal to 15 percent of the solids within the aeration basins.
4. MLSS of final aeration basin is representative of the MLSS of all the aeration basins. 9 × final aeration basin MLSS = total aeration solids.
5. Yield factor = 0.5 lbs MLSS solids produced/lb BOD removed.
6. Estimate primary effluent flow from recent records and actual flow data for first 8 to 10 hours of the day. Take into consideration whether the sludge wasting system is in operation.
7. Conversion factor = Yield × BOD:TOC ratio

   $1.1 = 0.5 \times 2.2$

SAMPLE WASTING FORMULA CALCULATIONS

1. Calculate the solids in the system in pounds. Since solids in the secondary clarifiers are 15 percent of the solids in the aeration basins, multiply the solids in the aeration basins by 1.15.

$$\begin{aligned}\text{Solids in System, lbs} &= \text{Aeration Volume, MG} \times \text{Final Aeration Cell MLSS, mg}/L \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times 1.15\\ &= 2.7\text{ M Gal} \times 2420\text{ mg}/L \times 8.34\text{ lbs/gal} \times 1.15\\ &= 62{,}668\text{ lbs}\end{aligned}$$

2. Estimate the solids produced in the system in pounds per day. Assume 1.1 pounds of solids are produced per pound of TOC.

$$\text{Solids Produced, lbs/day} = \frac{1.1\text{ lbs solids/day}}{1\text{ lb TOC/day}} \times \text{TOC, lbs/day}$$
$$= 1.1 \times \text{Flow, MGD} \times \text{TOC, mg}/L \times 8.34\text{ lbs/gal}$$
$$= 1.1 \times 3.3\text{ MGD} \times 554\text{ mg}/L \times 8.34\text{ lbs/gal}$$
$$= 16{,}772\text{ lbs solids/day}$$

3. Determine the desired pounds of solids in the system based on a MLSS set point of 2,200 mg/*L*. Assume solids in the secondary clarifiers are 15 percent of the solids in the aeration basins (multiply by 1.15).

$$\text{Desired Solids in System, lbs} = \text{Aeration Volume, MG} \times \text{MLSS Set Point, mg}/L \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times 1.15$$
$$= 2.7\text{ M Gal} \times 2{,}200\text{ mg}/L \times 8.34\text{ lbs/gal} \times 1.15$$
$$= 56{,}971\text{ lbs}$$

4. Calculate the sludge wasting amount in pounds per day.

$$\text{Sludge Wasting Amount, lbs/day} = \frac{(\text{Solids in System, lbs} - \text{Desired Solids in System, lbs})}{\text{Waste During 1 day}} + \text{Solids Produced, lbs/day}$$
$$= \frac{(62{,}668\text{ lbs} - 56{,}971\text{ lbs})}{1\text{ day}} + 16{,}772\,\frac{\text{lbs}}{\text{day}}$$
$$= 5{,}697\text{ lbs/day} + 16{,}772\text{ lbs/day}$$
$$= 22{,}469\text{ lbs/day}$$

NOTE: If the sludge wasting rate is negative, the MLSS is too low. Reduce the existing wasting rate by 10 to 15 percent. Some operators shut off the waste when negative values are obtained, but many operators try to avoid drastic changes in wasting rates by adjusting the existing wasting rate up or down by no more than 10 to 15 percent each day.

5. Determine the sludge wasting rate in MGD and GPM.

$$\text{Sludge Wasting Rate, MGD} = \frac{\text{Sludge Wasting Amount, lbs/day}}{\text{Waste Sludge SS, mg}/L \times 8.34\text{ lbs/gal}}$$
$$= \frac{22{,}469\text{ lbs/day}}{7{,}160\text{ mg}/L \times 8.34\text{ lbs/gal}}$$
$$= 0.376\text{ M gal/day}$$

$$\text{Sludge Wasting Rate, GPM} = \frac{376{,}000\text{ gal/day}}{1{,}440\text{ min/day}}$$
$$= 261\text{ GPM}$$

Waste sludge is first pre-thickened in dissolved air flotation (D.A.F.) units and mixed with primary sludge in the sludge holding tanks. Water is evaporated from the separated sludge mixture within the sludge drying plant and the product is currently marketed as a high vitamin B-12, high protein, animal feed supplement.

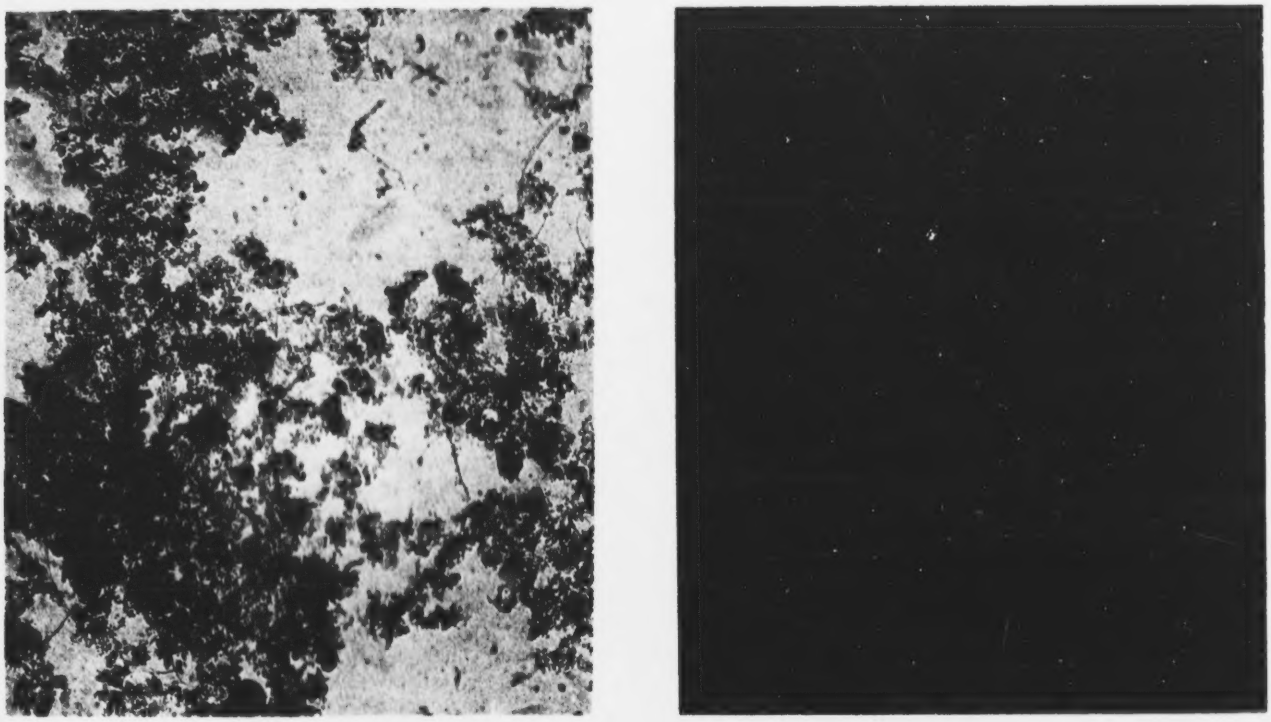
One last item that should be covered along with aeration basin control is the subject of aeration basin foam. At all times foam is present on the basin surfaces. Foam is a natural part of the biomass. A dark, greasy looking foam is the sign of an old sludge age while a white, clear foam is indicative of a young sludge age. Large quantities of foam can sometimes cause operational problems if the foam does not stay within the basins. Excessive foam can be caused by large quantities of detergents within the waste stream or some brewery materials such as yeast. Control of this foam can be achieved by: (1) decreasing air flow to the aerators, (2) by the use of chemical surfactants, or (3) by water sprays aimed to physically collapse the foam. A novel approach to foam control involves overflowing the aeration basin into a small side basin, letting the foam collapse and then wasting this foaming material from the plant.

2.567 Filamentous Organisms

Within brewery wastewater treatment plants, often the number one operational problem is the control of filamentous organisms (Fig. 2.18). Often sludge "bulking" is related to a filamentous bacteria by the name of *SPHAEROTILUS NATANS*. To blame all sludge bulking on this *ONE* type of filamentous organism is a misconception. In reality there are about 10 different types of filamentous organisms that can become predominant within *BREWERY* activated sludge and cause sludge settling problems. To a certain degree there is a relationship between the different filamentous organisms and specific operating conditions. Therefore, in some cases, if the type of filamentous organism can be identified, the causative operating condition can also be determined and rectified. However, this approach is usually not practical. To begin with, specific filamentous organism identification requires 500X — 1,000X power microscope. Also, even if the specific filament can be identified, the literature relating filament type to causative condition is somewhat limited.

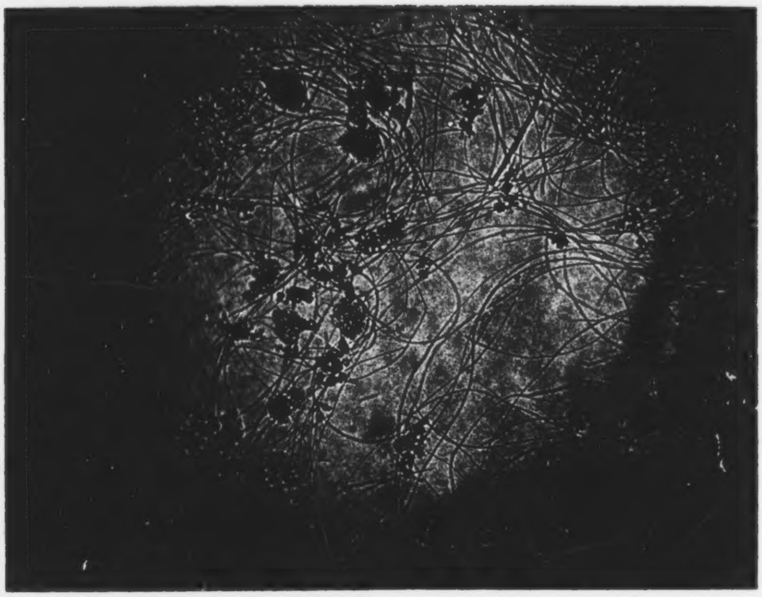
A more successful approach to filamentous organisms management, as reported within the literature is described as follows: (It should be noted that only *SOME* of the techniques described have been used at the plant described here.)

1. Determine if filamentous organisms are the true culprit. This can usually be done by examining a sludge sample with a relatively inexpensive microscope. The filamentous organisms look like fine "hairs" or "wires" extending out of the sludge floc particles or they can be found in the liquor floating free. Some filaments are always present, but if they appear to be 20 percent of the biomass or more, they could be causing settling problems.
2. A "short term" corrective step is often necessary to halt immediate "bulking." Many process adjustments can be done to bring the filaments under control:
    a. Careful polymer or chemical ($FeCl_3$) dosage to prevent SS loss within the secondary clarifiers.
    b. Excessive sludge wasting to remove filamentous organisms from the system.
    c. Chemical dosage of the return sludge with oxidants such as H_2O_2 (0.1 lb H_2O_2/1 lb. VSS) or Cl_2 (3 to 5 lbs Cl_2/1000 lbs VSS).
3. Develop a "long-term" control program to correct operational problems and to prevent the recurrence of filamentous organisms. A list of common causes of filamentous "bulking" is as follows:
    a. Low DO levels within aeration basins and secondary clarifiers (this is often a *RESULT* of a high F/M ratio, although the F:M ratio alone is not necessarily the problem).



1. Typical brewery activated sludge, few filaments

2. Brewery activated sludge, some filaments



3. Typical highly filamentous sludge

Fig. 2.18 Filamentous organisms (100 × magnification)

b. A lack of adequate nutrients (nitrogen or phosphorus) or trace minerals within the influent.

c. The presence of high levels of sulfur within the influent.

d. Low F/M levels within aeration system (less than 0.2).

e. Large fluctuations within the plant influent organic loading.

Many of these problems can be overcome by implementing operational changes and by engineering design changes. At the wastewater treatment plant under examination here, many changes have been made to control the growth of filamentous organisms. Experimentation has revealed that the dissolved oxygen concentration (DO) is the most influential factor that affects filamentous organism growth within this plant. Since some filamentous organisms are often desirable (to maintain floc structure), a desired *DO LEVEL SET POINT* is used to *ADJUST FILAMENT CONCENTRATIONS*. Over a long period of time, experience has shown that filamentous organism concentrations can be adjusted by adjusting "contact" cell DO levels. *AN INCREASED DO LEVEL* (5 to 10 mg/*L*) will yield *A DECREASE IN FILAMENTOUS ORGANISMS. A DECREASED DO LEVEL* (1 to 3 mg/*L*) will result in an *INCREASED NUMBER OF FILAMENTOUS ORGANISMS.*

2.568 Laboratory Testing

Only a small portion of the testing within a brewery wastewater treatment plant is devoted to "permit" monitoring requirements. The majority of the laboratory time is spent obtaining test data that is required to assist in making process control adjustments. Numerous MLSS measurements are made to evaluate sludge wasting needs and sludge settling characteristics. Plant loading data is updated daily by the use of Total Organic Carbon (TOC) analysis. Nutrient concentrations are measured at several locations within the plant to assist with nutrient addition calculations. Both 24-hour composite samples and grab samples are used to obtain representative data. Microphotographs (Fig. 2.18) of sludge samples from several locations within the aeration system serve as a permanent record of microorganism diversity and relative filamentous organism concentrations. Many additional quantitative and qualitative tests are performed and the results are recorded. This data, along with numerous other measurements and evaluations recorded throughout the wastewater treatment plant serve as the basis for mapping out operational control strategies and are indispensable.

2.569 Recordkeeping

Every wastewater treatment plant is different and requires different types of testing and record keeping. There is no substitute for well organized laboratory data and operational log sheets. The extreme value of this information cannot be over emphasized. Well recorded data can serve as a quick update to an operator coming on shift or it may be graphed, charted, or tabulated to indicate more clearly overall trends. Proper use and analysis of records have allowed the operators of plants treating brewery wastes to produce a high quality effluent.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 111.

2.56A Why are primary clarifiers not very effective in removing BOD from brewery wastes?

2.56B Where are nutrients added and how are nutrients added when treating brewery wastes?

2.56C What factors influence the MLSS level in the aeration basins?

2.56D How is the sludge wasting rate determined?

2.56E How can filamentous "bulking" be controlled in activated sludge plants treating brewery wastes?

2.57 Food Processing Wastes

This section discusses how to treat wastewaters from two different types of food processing wastes. Treatment of artichoke wastewater and dairy wastes are presented by two operators who actually treat these wastes on a day-to-day basis. Almost all of the foods we eat (fruits, vegetables, fish, meats, dairy products) produce wastewaters when they are processed for consumption. Treatment of these wastewaters may be unique for each food, but the basic principles of pretreating the wastewater to produce an environment suitable for activated sludge treatment are similar.

2.570 Treatment of Artichoke Wastewater by Peter Luthi

Processing of artichokes in California is a year round operation with a major peak during the months of March, April and May and a minor peak in September, October and November. The fact that some wastewater is generated all year round makes the operation of an activated sludge system possible at this pretreatment facility (Fig. 2.19). The effluents from the activated sludge plant which treats high strength wastewater, the flotation unit which treats medium strength wastewater, and cooling water with a low BOD load are all discharged into the sewer for final treatment by the municipal wastewater treatment plant.

Wastewaters from the artichoke processing plant are segregated according to BOD strength and only the highest BOD portion of the wastewater is treated by the activated sludge system (Fig. 2.19). Primary objectives of the activated sludge treatment process are to:

1. Treat the high strength (high BOD) waste to acceptable levels with a minimum of input (energy, labor, dollars) and a minimum of waste sludge produced, and
2. Produce a treated effluent that is discharged to a municipal treatment plant that meets the following discharge limits:
   a. BOD <500 mg/*L*,
   b. Suspended solids <500 mg/*L*, and
   c. pH within a range of 6 to 9.

BOD strength of the wastewater treated varies between 1,000 and 15,000 mg/*L* with a pH of around 4.5 (from the use of vinegar and citric acid in the process). Volume of high strength BOD water ranges from 1,500 gal/week to 15,000 gal/week (5.7 to 57 cu m/week) during the peak season.

2.571 Pilot Project

The unusually high and widely fluctuating BOD levels of the waste required that the feasibility of an activated sludge system be studied on a pilot project. An activated sludge system

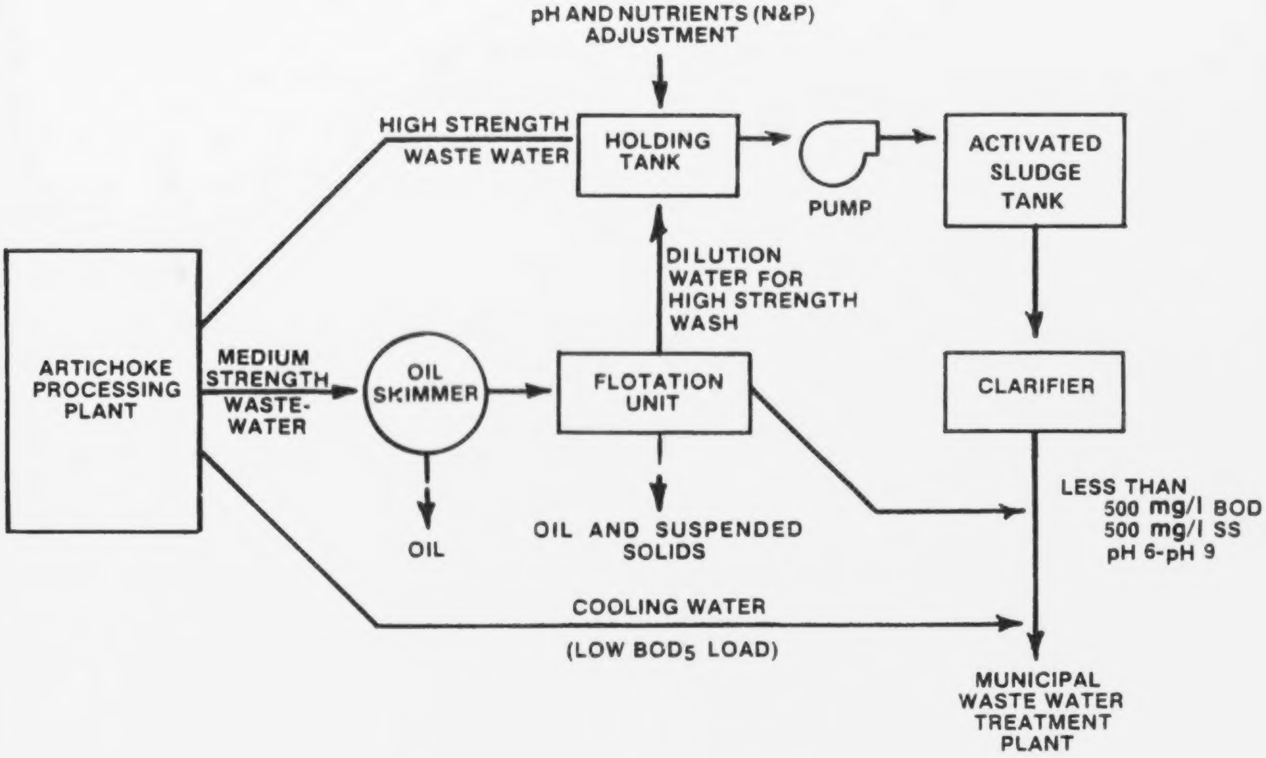

pH AND NUTRIENTS (N&P)
ADJUSTMENT
HIGH STRENGTH
WASTE WATER
HOLDING
TANK
PUMP
ACTIVATED
SLUDGE
TANK
DILUTION
WATER FOR
HIGH STRENGTH
WASH
ARTICHOKE
PROCESSING
PLANT
MEDIUM
STRENGTH
WASTE-
WATER
OIL
SKIMMER
FLOTATION
UNIT
CLARIFIER
OIL
OIL AND SUSPENDED
SOLIDS
LESS THAN
500 mg/l BOD
500 mg/l SS
pH 6-pH 9
COOLING WATER
(LOW BOD5 LOAD)
MUNICIPAL
WASTE WATER
TREATMENT
PLANT

Fig. 2.19 Artichoke activated sludge pretreatment facility

with extended aeration using mean cell residence times up to 15 days was chosen. As much as 90 to 95 percent BOD removal could be achieved if the influent BOD was kept below 6,000 mg/L. Higher influent BODs resulted in lower effluent quality. Medium strength wastewater is therefore used to dilute the influent.

To accumulate some operating data during the pilot project, the following analyses were performed on a daily basis:

1. Influent and effluent COD and suspended solids,
2. Mixed liquor suspended solids,
3. pH of influent, mixed liquor and effluent,
4. Dissolved oxygen, and
5. SVI

COD rather than BOD was chosen for its relatively easy and fast analysis. A graph showing 15-day moving average influent COD, mixed liquor, suspended solids, moving F/M ratio, effluent COD and suspended solids was drawn and kept up daily to find the best operating guidelines. Fifteen-day moving averages for influent COD and F/M ratio were computed to reduce the effect of fluctuating daily results.

2.572 Daily Operational Procedures

Through trial and error, and after several upsets over a nine-month period, it was readily visible from the graph and data accumulated that acceptable results (less than 500 mg/L BOD and suspended solids) were obtainable when the F/M ratio was kept between 0.08 to 0.28 pounds BOD/day/pound MLVSS.

Daily influent and effluent COD and pH, mixed liquor and effluent suspended solids analyses are performed. Also, determing the SVI on a daily basis is helpful in detecting changes in the settling characteristics of the activated sludge. Sludge volume indeces were, however, generally higher than data given in literature for municipal treatment plants.

Nutrients (N and P, in the form of ammonium phosphate fertilizer) were initially added in batches on a daily basis. However, a continuous addition directly into the in-feed line used later on proved much more reliable and provided for a smoother operation. Lack of sufficient nutrients was responsible for bad settling characteristics in several cases. If the SVI increases and lack of nutrients is suspected, a look at the sludge under the microscope should be taken. The presence of filamentous bacteria will confirm the suspicion. Sufficient amounts of nutrients proved to be quite important and upsets caused by their lack took a long time to remedy. No provision for chlorinating the return sludge exists. No adverse effects were observed by the addition of too much nitrogen and phosphorus.

To keep influent COD concentration as steady as possible on a day-to-day basis, dilution with medium strength wastewater is used when needed.

The fluctuating concentrations of the influent COD make it necessary to keep the DO level in the aerator between 4.0 and 6.0 mg/L. Rapid changes occur sometimes and can drop DO levels to as low as 2.0 mg/L in a matter of hours. Therefore, keeping levels at 4.0 to 6.0 mg/L assures that the DO does not drop below the critical 2.0 mg/L.

Effluent pH monitoring shows that when effluent pH drops below 6.5 it is necessary to adjust the influent pH to between 5.5 and 6.5. This is done with granular sodium hydroxide added to the holding tank. At times of low feed rates, however, the system is able to tolerate the normal influent pH of 4.2 to 4.8 and only occasionally are adjustments necessary.

Influent levels vary from 4,300 gal/day to 8,600 gal/day (16 to 32 cu m/day). Levels higher than 8,600 gal/day (32 cu m/day) produce turbulence in the clarifiers with accompanying solids loss in the effluent. Mixed liquor solids vary from 3,000 to 4,500 mg/L. Influent volume is the most important variable used to control the system. By increasing or reducing the volume, the F/M ratio can be increased or decreased more gradually or kept at one level when influent COD concentration changes. In anticipation of heavy production times and coinciding larger amounts of wastewater, mixed liquor solids are allowed to build up to 4,500 mg/L and the F/M ratio increases which allows treatment of larger volumes with higher concentrations of COD. Sludge must now be wasted on a daily basis to keep the aerator solids level (MLSS) at 4,500 mg/L. Waste sludge is disposed of on land.

Immediately following heavy production, sludge is wasted at an increased rate to reduce mixed liquor solids to 3,000 mg/L to avoid starvation of the system now that COD concentration and waste volume are dropping. During times of low production the F/M ratio is reduced to around 0.08 lbs BOD/day/lb MLVSS. At this level of subsistence, when influent BOD level and feed rate are at their lowest, the effluent produced is of a lower quality. More solids than usual are being carried away with the effluent and sludge wasting only has to be done on an occasional basis. However, the primary objectives of reducing effluent BOD and suspended solids levels below 500 mg/L can still be achieved.

2.573 Treatment of Dairy Wastes by Ralph L. Robbins, Jr.

Dairy wastes can be treated by the various modes of the activated sludge process. Many dairy waste treatment plants have the designed flexibility to treat by either:

1. Extended aeration,
2. Contact stabilization, or
3. Step-feed aeration.

On the basis of actual operating experience and analysis of influent, plant and effluent samples, the extended aeration mode appears to work best for some plants.

2.574 Plant Influent

Dairy wastewaters are comprised of production materials such as lactose, calcium lactate and protein hydrolysates. The sanitary facilities at many plants are separate from the industrial dairy wastes and do not enter the wastewater stream to the treatment facility. Thus chlorination of the effluent is not necessary. The influent averages a BOD loading of 3,000 lbs per day (1,360 kg/day) and a total solids level of approximately 3,500 lbs per day (1,590 kg/day). The treatment facility (Fig. 2.20) operates throughout the entire year with little change of temperature in the aeration tanks. The effluent temperature does not fall below 60°F (15°C) year round, thus providing for a stable operation all year.

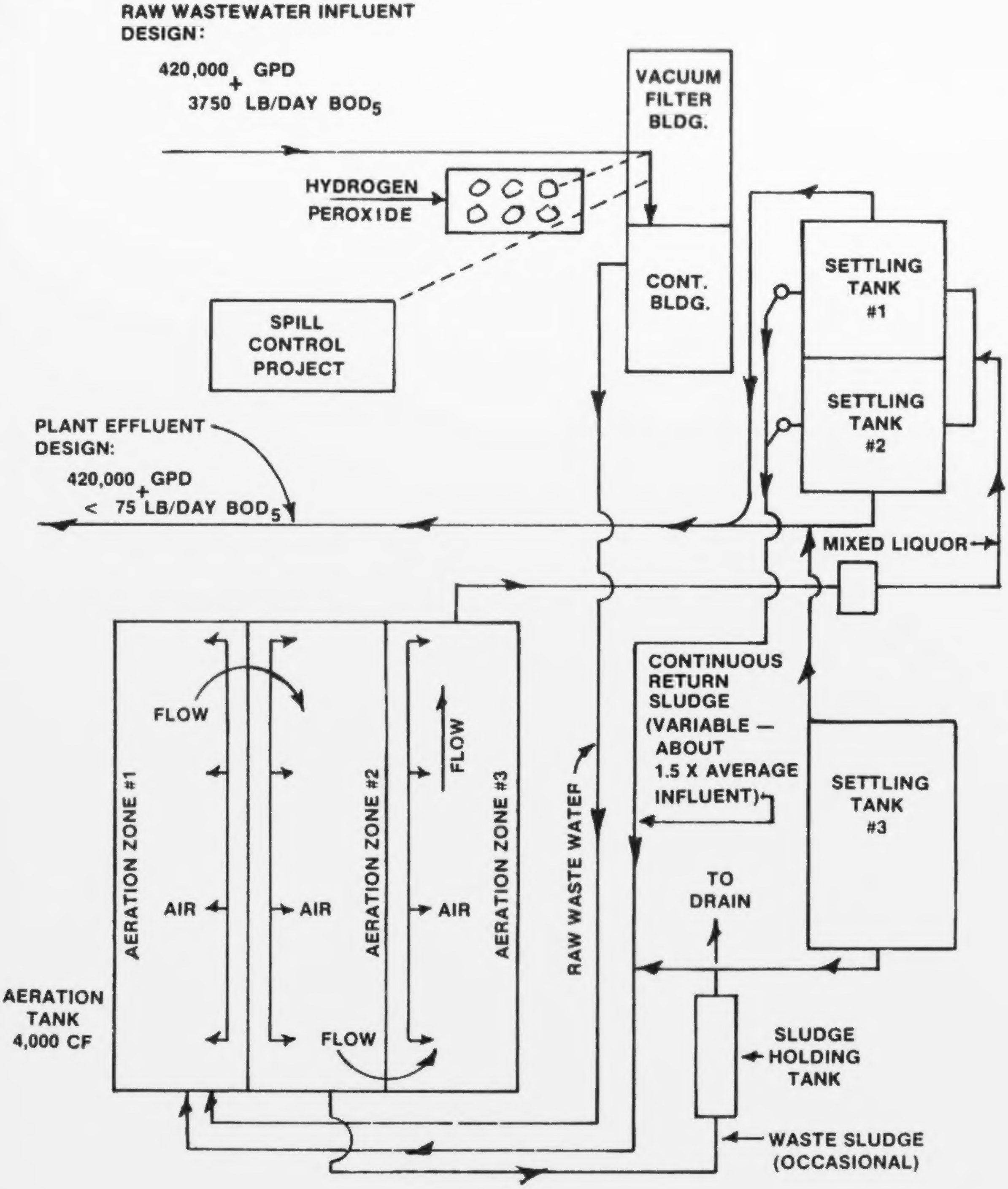

RAW WASTEWATER INFLUENT
DESIGN:
420,000 GPD
+
3750 LB/DAY BOD_5
VACUUM
FILTER
BLDG.
HYDROGEN
PEROXIDE
CONT.
BLDG.
SETTLING
TANK
#1
SETTLING
TANK
#2
SPILL
CONTROL
PROJECT
PLANT EFFLUENT
DESIGN:
420,000 GPD
+
< 75 LB/DAY BOD_5
MIXED LIQUOR
FLOW
FLOW
AERATION ZONE #1
AERATION ZONE #2
AERATION ZONE #3
AIR
AIR
AIR
FLOW
RAW WASTE WATER
CONTINUOUS
RETURN
SLUDGE
(VARIABLE —
ABOUT
1.5 X AVERAGE
INFLUENT)
SETTLING
TANK
#3
TO
DRAIN
AERATION
TANK
4,000 CF
SLUDGE
HOLDING
TANK
WASTE SLUDGE
(OCCASIONAL)

Fig. 2.20 Dairy waste activated sludge treatment facility

2.575 Operation

Aeration tanks may be operated in the extended aeration mode. Some dairy wastes require at least 18 hours aeration time in the tanks. Up to 80 percent of the BOD load can be reduced in the first tank with the other two tanks treating the remaining 20 percent. For this reason the diffuser capability in the first tank should be twice that of the other two tanks.

The mixed liquor suspended solids level in the aeration tanks are kept at a high level of 1 percent or 10,000 mg/*L*. This high level of MLSS is necessary to prevent process upsets caused by shock organic loadings. Extra air capacity is necessary in case of shock organic loadings in order to keep aeration tank DO levels between 2 to 6 mg/*L*.

Settling tank detention times can be as long as 8 hours. Activated sludge is recirculated to the aeration tanks at a rate of 1½ to 2 times the plant influent rate.

Vacuum filters are used to dewater the sludge. Lime and ferric chloride are added for flocculation of the waste sludge before filtering. The sludge cake runs from 20 to 30 percent dry solids. The waste sludge cake is disposed of at a sanitary landfill site.

2.576 Plant Effluent

Plant effluent is monitored daily by plant personnel. Analytically the BOD, SS, COD, phosphorus, nitrate, nitrite and total nitrogen are monitored.

2.577 Operational Techniques for Upgrading Effluent

Problems can develop with milk protein breakdown. The addition of 50 mg/*L* of anhydrous ammonia can produce a complete breakdown of milk protein in the aeration tanks. Activated carbon can help in many areas, including odor control, removal of phosphate, media for extra bacteria growth in the aeration tanks and an aid in flocculation and settling in the clarifiers.

A fermentor can be used to grow commercial bacteria for injection into aeration tanks during times of bacteria kill due to shock loadings from major spills in the production area. Installation of a system for the addition of hydrogen peroxide for odor control and additional oxygen during times of shock loadings can be helpful.

A spill control system which diverts major spills into a pretreatment holding tank for pH adjustment and pre-aeration before being blended into the main aeration tanks can be used if there is adequate warning.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 111.

2.57A How are high strength artichoke waste influents (BOD >6,000 mg/*L*) adjusted before being treated by the activated sludge process?

2.57B Why were 15-day moving averages computed and plotted for artichoke influent COD and F/M ratio?

2.57C What chemical can be used to provide nutrients for the treatment of artichoke wastes?

2.57D Why might the chlorination of the effluent from a dairy waste treatment plant not be necessary?

2.57E Why are high levels of MLSS (10,000 mg/*L*) kept in aeration tanks that treat dairy wastes?

PETROLEUM INC

2.58 Petroleum Refinery Wastes by Cal Davis

2.580 Refinery Wastewater Characteristics

Three main compounds, ammonia, phenols and sulfide, are found in petroleum refining wastewater and can be treated very effectively by the activated sludge process.

Influent flows can vary both in rate and contaminant concentration, very rapidly and without notice. Waste treatment plants with holding ponds can control hydraulic loadings, but not always BOD loadings. To some extent hydraulic loading can be used to control BOD loading with the MLVSS remaining constant in the aeration basin. In the event of a shock load, a hydraulic loading change would be the first corrective step.

2.581 Activated Sludge Process

Understanding and monitoring the activated sludge process is important in treating petroleum refining wastewater. Recognizing that each plant operates differently, most petroleum treatment activated sludge units (Fig. 2.21) operate on extended aeration mode with MCRTs up to 30 days in order to maintain the nitrification population necessary to oxidize ammonia. The minimum MCRT for good nitrification seems to be 20 days.

2.582 Frequency of Sampling and Lab Tests

Wastewater from a refinery can change in flow rate and waste concentration very suddenly. Certain tests must be run each shift while others can be run daily. Tests that need to be run each shift at the treatment plant include DOs, temperature, pH, sulfide, phenols, ammonia, and 30-minute settleability. During upset conditions these tests need to be run at least twice a shift. Tests that need to be run each day include TOC or COD, BOD, MLTSS, MLVSS, recycle sludge TSS, ammonia, phenols, pH, PO_4 and oil.

2.583 Operational Procedures

When you come on duty after a shift change, visually inspect the activated sludge process, and review the log book and lab sheet for any changes in influent rates or concentrations. Check the following items: hydraulic loading, DOs, aeration basin, MLTSS and MLVSS, pH, temperature of influent, sludge recycle rate and clarifier loading. For comparison purposes measure sludge settleability and also calculate the SVI and F/M ratio. Under normal conditions DOs are 1.5 to 2.0 mg/*L*, pH from 6.8 to 7.0, and phenols, ammonia and sulfide are nil.

2.584 Response to Sulfide Shock Load

If a check of the activated sludge system shows DOs less than 0.5 mg/*L*, pH of 5.6, aeration basin turning a light color, and phenols showing in effluent, then a sulfide shock is indicated. Testing may show no phenols in influent stream since

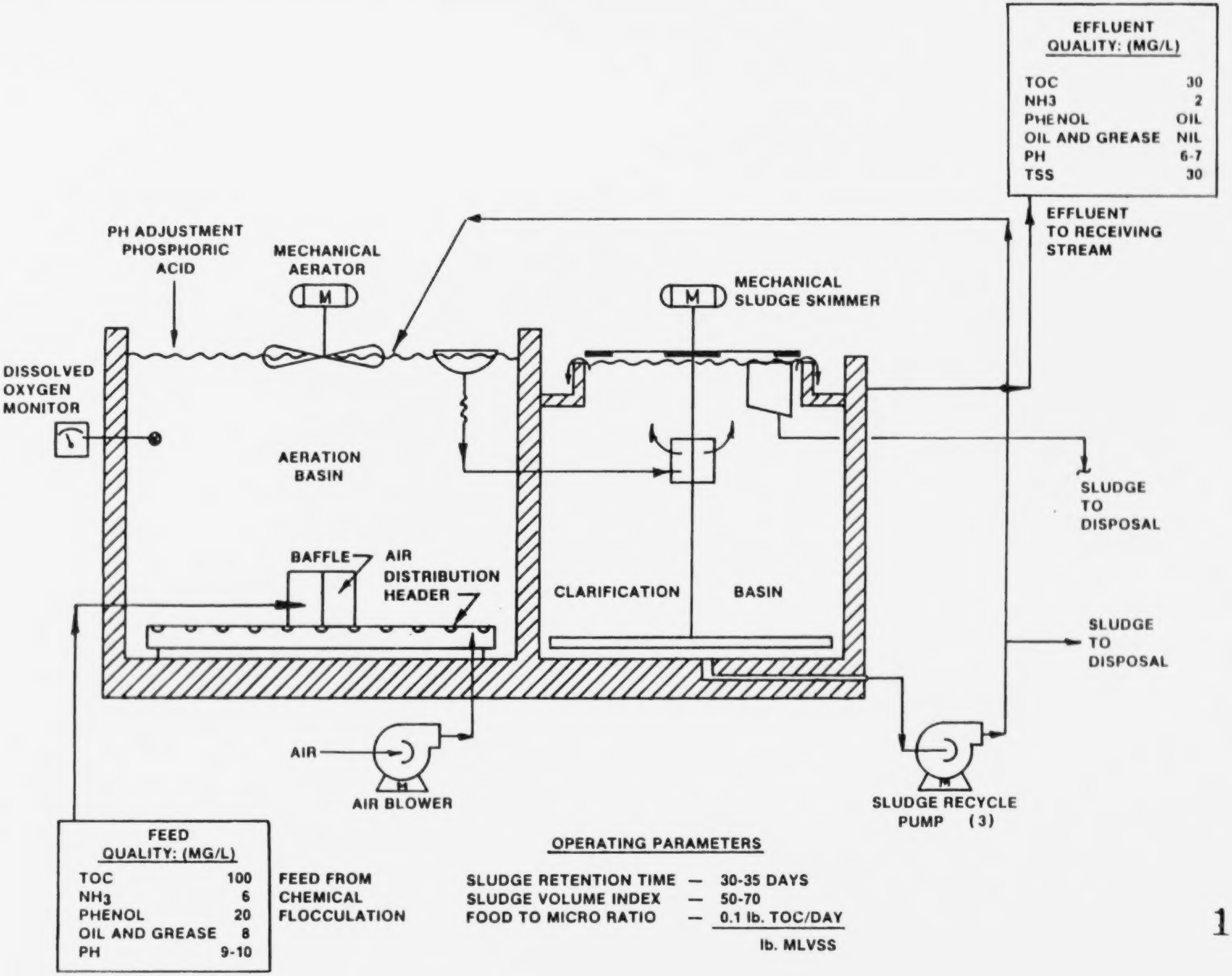

EFFLUENT QUALITY: (MG/L)
TOC 30
NH3 2
PHENOL OIL
OIL AND GREASE NIL
PH 6-7
TSS 30
EFFLUENT TO RECEIVING STREAM
PH ADJUSTMENT PHOSPHORIC ACID
MECHANICAL AERATOR
M
MECHANICAL SLUDGE SKIMMER
M
DISSOLVED OXYGEN MONITOR
AERATION BASIN
SLUDGE TO DISPOSAL
BAFFLE
AIR DISTRIBUTION HEADER
CLARIFICATION BASIN
SLUDGE TO DISPOSAL
AIR
AIR BLOWER
SLUDGE RECYCLE PUMP (3)
FEED QUALITY: (MG/L)
TOC 100
NH3 6
PHENOL 20
OIL AND GREASE 8
PH 9-10
FEED FROM CHEMICAL FLOCCULATION
OPERATING PARAMETERS
SLUDGE RETENTION TIME — 30-35 DAYS
SLUDGE VOLUME INDEX — 50-70
FOOD TO MICRO RATIO — 0.1 lb. TOC/DAY / lb. MLVSS

Fig. 2.21 Refinery waste activated sludge process

sulfide tends to mask or interfere with the phenol test. To correct this problem, the hydraulic loading needs to be reduced until DOs are above 1.5 mg/*L* and soda ash should be added to the aeration basin to bring the pH above 6.2 in order to reactivate the phenol eaters. If phenols in the effluent are near your NPDES limit, adding hydrogen peroxide (H_2O_2) can be beneficial.

2.585 Correcting Excessive Phenols

Phenols in excess may pose more of a problem with odor and in extreme cases of phenol shock, microbes will stop working and DOs will increase to the saturation limit. To correct this problem, a decrease in hydraulic loading is necessary and if phenols in the effluent are near the NPDES limit, the addition of H_2O_2 will help to oxidize the phenols.

2.586 Treating Ammonia

Ammonia can be very troublesome since it is related directly to fish toxicity. Ammonia can be difficult to biologically treat because it is difficult to cultivate nitrifying organisms to degrade ammonia. Besides the free ammonia, two other problem compounds that can show up in petroleum refining wastewater are monoethanolamine (MEA) and thiocyanate. Both of these compounds are biologically degraded to ammonia. Lab results must be checked each shift for an indication of a potential increase in ammonia and the maintaining of an MCRT or environment that is conducive to cultivating nitrifying bacteria.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 111.

2.58A What are the three main petroleum refinery waste compounds that can be treated by the activated sludge process?

2.58B Why are MCRTs as high as 30 days necessary to treat petroleum refinery wastes?

2.58C How can a shock load of phenols be treated?

2.59 Summary and Acknowledgments

2.590 Summary

The basic treatment unit in the activated sludge process is a biological reactor (aerated basin or pond). This reactor provides an environment for the conversion of soluble organic material into insoluble microorganism cells. The subsequent unit is a secondary clarifier or pond where the cells are allowed to settle. The settled cells, or sludge, may be either returned to the aeration system, wasted from the system, or stored. As the result of biological growth, large volumes of organic solids are generated in secondary treatment processes.

Although several different activated sludge systems are used to provide secondary treatment (See Sections 11.05 and 11.9) for industrial, domestic, and domestic-industrial wastewaters, the control strategies and/or operating guidelines are essentially the same.

This section has described conditions unique to the treatment of industrial wastewater. Control of your activated sludge system will be enhanced by using the information for the operation and control of your plant contained in various sections of Chapters 8 and 11 of Volumes I and II and this chapter.

2.591 Acknowledgments

Portions of Section 2.50 through 2.54 were taken from "Pollution Abatement in the Fruit and Vegetable Industry" (Volumes 1, 2, and 3), EPA Technology Transfer Seminar Publication, U.S. Environmental Protection Agency, Center for Environmental Research Information, 26 West St. Clair Street, Cincinnati, Ohio 45268.

The representatives of industry who prepared these sections on how to treat industrial wastes are sincerely thanked. Without the contributions from James J. McKeown, Clifford J. Bruell, Peter Luthi, Ralph L. Robbins, Jr., and Cal Davis, this section would not have appeared in this manual.

2.6 EFFLUENT NITRIFICATION

2.60 Need for Effluent Nitrification

Many activated sludge processes are designed to attain a high degree of nitrification. The degree of nitrification that must be attained is dictated by the maximum allowable limit of ammonia nitrogen discharged with the final effluent. This limit is usually governed by the NPDES permit issued by state or federal regulatory agencies.

Nitrogenous compounds discharged from wastewater treatment plants can have several harmful effects. These impacts include ammonia toxicity to fish life, reduction of chlorine disinfection efficiency, an increase in the dissolved oxygen depletion in receiving waters, adverse public health effects (mainly groundwater), and a reduction in the suitability for reuse.

Nitrogen concentrations in raw municipal wastewaters generally range from 15 to 50 mg/*L*, of which approximately 60 percent is ammonia-nitrogen, 40 percent is organic nitrogen, and a negligible amount (one percent) is nitrite and nitrate-nitrogen.

2.61 Nitrogen Removal Methods

Ammonia nitrogen can be reduced in concentration or removed from wastewater by several processes. These processes can be divided into two broad categories: physical-chemical methods and biological methods.

This section is devoted mainly to biological nitrification. A brief discussion of some physical-chemical nitrogen removal methods also is included.

2.610 Ammonia Stripping

The ammonia nitrogen which is present in wastewater during conventional biological treatment can be removed by a physical process called desorption (stripping). Simply stated, the wastewater is first made very alkaline by adding lime, and the ammonia is then induced to leave the water phase and enter the gas phase where it is released to the atmosphere. To accomplish this stripping, the wastewater is contacted with a sufficient quantity of ammonia-free air. This contacting with air is done in a slat-filled tower very similar to those used by industry to cool water.

2.611 Ion Exchange

This nitrogen removal process involves passing ammonia-laden wastewater through a series of columns packed with a material called clinoptilolite. The ammonium ion adheres to or is absorbed by the clinoptilolite. When the first column in a series loses its ammonia adsorptive capacity, it is removed from the treatment scheme and washed with limewater. This step converts the captured ammonium ions to ammonia gas, which is then released to the atmosphere by contacting heated air with the wastewater stream, in much the same manner as described under ammonia stripping.

2.612 Breakpoint Chlorination

Breakpoint chlorination (superchlorination) for nitrogen removal is accomplished by adding chlorine to the wastewater in an amount sufficient to oxidize ammonia-nitrogen to nitrogen gas. After sufficient chlorine has been added to oxidize the organic matter and other readily oxidizable substances present, a stepwise reaction of chlorine with ammonium takes place. This may be the simplest nitrogen removal process, yet it has some disadvantages. In practice, approximately 10 mg/*L* of chlorine is required for every 1 mg/*L* of ammonia-nitrogen. In addition, acidity produced by the reaction must be neutralized by the addition of caustic soda or lime which add greatly to the total dissolved solids in the wastewater.

2.62 Biological Nitrification

The nitrogen present in wastewater predominates as ammonia and organic nitrogen. As the organic matter in the wastewater decomposes, a portion of the organic nitrogen is converted to ammonia nitrogen. When the wastewater is sufficiently aerated, the nitrite forming bacteria (nitrosomonas) will oxidize the ammonia-nitrogen to nitrite-nitrogen. The nitrate forming bacteria (nitrobacter) then oxidize the nitrite-nitrogen to nitrate-nitrogen. Nitrate represents the final form of nitrogen resulting from the oxidation of nitrogenous compounds in the wastewater. The wastewater nitrogen cycle is shown in Figure 2.22.

2.63 Factors Affecting Biological Nitrification

Because of current ammonia removal requirements and anticipation of future "complete nitrogen removal" requirements, you may be required to operate such an activated sludge plant. If you are operating a plant of this type, there are seven principal control guidelines that you must consider to maintain the nitrification process at optimum performance levels:

1. Dissolved oxygen,
2. pH,
3. Wastewater temperature,
4. Nitrogenous food,
5. Detention time,
6. MCRT, F/M, or sludge age, and
7. Toxic materials.

Each of these guidelines must be properly controlled for the successful operation of a biological nitrification process.

1. Dissolved Oxygen (DO)

Nitrification exerts a substantial oxygen requirement. Each pound of ammonium-nitrogen that is nitrified requires approximately 4.6 pounds of oxygen (4.6 kg O_2/kg NH_4^+-N).

Nitrification appears to be uninhibited at DO concentrations of 1 mg/*L* or more. To insure adequate nitrification, the DO in the aeration tank must usually be maintained between 1.0 to 4.0 mg/*L* under average loading conditions. This will include a reasonable DO safety factor. Under peak loading, the DO may fall off somewhat, yet should never fall below 1.0 mg/*L*.

The oxygen requirement may be calculated as shown in the following example.

EXAMPLE

Determine the oxygen requirements for the effluent from a 10 MGD activated sludge plant with an average five-day BOD of 30 mg/*L* and an average ammonium-nitrogen concentration of 15 mg/*L*.

Known		**Unknown**
Flow, MGD	= 10 MGD	Oxygen Requirement, lbs/day
BOD, mg/*L*	= 30 mg/*L*	
NH_4^+-N, mg/*L*	= 15 mg/*L*	

1. Calculate the ammonium-nitrogen load in pounds per day.

$$\begin{aligned} NH_4^+\text{-N Load, lbs/day} &= \text{Flow, MGD} \times NH_4^+\text{-N, mg/}L \times 8.34 \text{ lbs/gal} \\ &= 10 \text{ MGD} \times 15 \text{ mg/}L \times 8.34 \text{ lbs/gal} \\ &= 1{,}251 \text{ lbs } NH_4^+\text{-N/day} \end{aligned}$$

2. Calculate the BOD load in pounds per day.

$$\begin{aligned} \text{BOD, lbs/day} &= \text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34 \text{ lbs/gal} \\ &= 10 \text{ MGD} \times 30 \text{ mg/}L \times 8.34 \text{ lbs/gal} \\ &= 2{,}502 \text{ lbs BOD/day} \end{aligned}$$

3. Calculate the ammonium-nitrogen oxygen requirement (pounds per day of oxygen to oxidize ammonia (NH_3) to nitrate (NO_3^-).

$$\begin{aligned} \text{Oxygen, lbs/day } (NH_4^+\text{-N}) &= NH_4^+\text{-N, } \frac{\text{lbs}}{\text{day}} \times \frac{4.6 \text{ lbs Oxygen}}{\text{lb } NH_4^+\text{-N}} \\ &= 1251 \frac{\text{lbs } NH_4^+\text{-N}}{\text{day}} \times \frac{4.6 \text{ lbs Oxygen}}{\text{lb } NH_4^+\text{-N}} \\ &= 5{,}755 \text{ lbs Oxygen/day} \end{aligned}$$

4. Calculate the BOD oxygen requirement.

$$\begin{aligned} \text{Oxygen, lbs/day (BOD)} &= \text{BOD, } \frac{\text{lbs}}{\text{day}} \times \frac{1.5 \text{ lbs Oxygen}}{\text{lb BOD}} \\ &= 2502 \frac{\text{lbs BOD}}{\text{day}} \times \frac{1.5 \text{ lbs Oxygen}}{\text{lb BOD}} \\ &= 3{,}753 \text{ lbs Oxygen/day} \end{aligned}$$

5. Calculate the total oxygen requirement to properly oxidize ammonium nitrogen (NH_4^+ -N) and biochemical oxygen demand (BOD).

$$\begin{aligned} \text{Total Oxygen Requirement, lbs/day} &= \text{Oxygen, lbs/day } (NH_4^+\text{-N}) + \text{Oxygen, lbs/day (BOD)} \\ &= 5{,}755 \text{ lbs/day} + 3{,}753 \text{ lbs/day} \\ &= 9{,}508 \text{ lbs/day} \end{aligned}$$

Because the rate of nitrification will vary significantly with temperature and pH, compensation must be made for these variations. During the summer months, the following methods can be used to match the oxygen requirement to your plant's oxygen capability. These methods attempt to provide more oxygen for nitrification while trying to reduce other oxygen demands.

a. Reduce the aeration system MLSS concentration.

b. Reduce the wastewater pH by reducing chemical addition (if used).

c. Reduce the number of tanks in service while increasing oxygen supply to the tanks remaining in service.

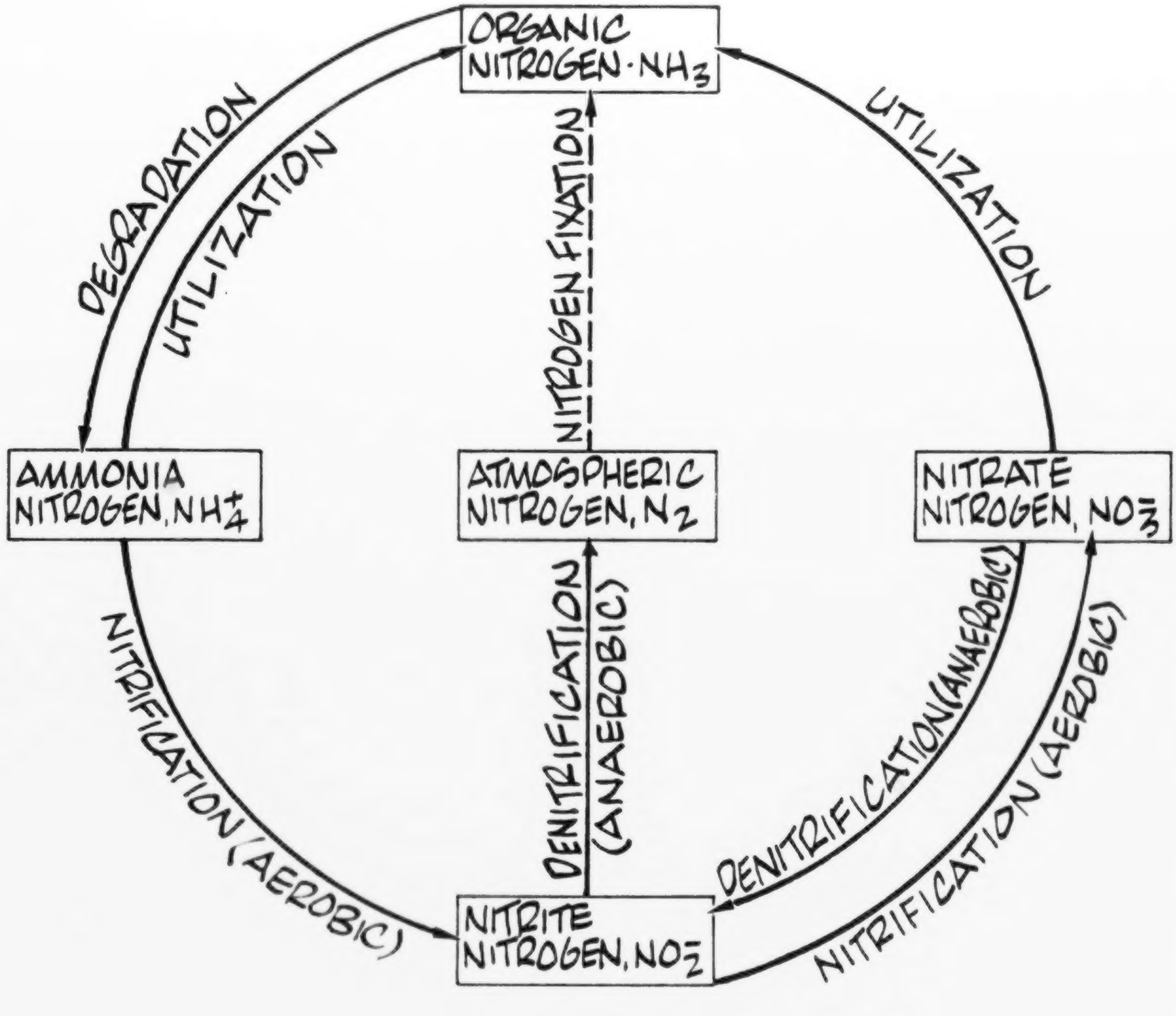

ORGANIC NITROGEN·NH3
DEGRADATION
UTILIZATION
NITROGEN FIXATION
UTILIZATION
AMMONIA NITROGEN, NH4+
ATMOSPHERIC NITROGEN, N2
NITRATE NITROGEN, NO3-
NITRIFICATION (AEROBIC)
DENITRIFICATION (ANAEROBIC)
DENITRIFICATION (ANAEROBIC)
NITRIFICATION (AEROBIC)
NITRITE NITROGEN, NO2-

Fig. 2.22 Wastewater nitrogen cycle

2. pH

In many wastewaters, there is insufficient alkalinity initially present to leave a sufficient residual for buffering the wastewater during the nitrification process. The significance of pH depression in the process is that nitrification rates are rapidly depressed as the pH is reduced below 7.0. Because of the effect of pH on nitrification rate, it is especially important that there be sufficient alkalinity in the wastewater to balance the acid produced by nitrification. A pH of between 7.5 and 8.5 is considered optimal. Approximately 7.2 pounds of alkalinity are destroyed per pound (7.2 kg/kg) of ammonia-nitrogen (NH_3-N) oxidized. Caustic or lime addition may be required to supplement moderately alkaline wastewaters.

If it becomes necessary to add chemicals (preferably lime) for pH adjustment, the required quantities of chemical will vary with wastewater temperature, MLVSS concentration, influent ammonia-nitrogen concentration and the natural alkalinity of the wastewater. As the oxidation of ammonia-nitrogen to nitrate-nitrogen destroys approximately 7.2 pounds of alkalinity per pound (7.2 kg/kg) of ammonia-nitrogen, this loss of alkalinity must be added to the chemical quantity calculated for pH adjustment. For operation under the most adverse temperature and pH conditions, sufficient lime must be added initially to raise the pH into the desired range, and then 5.4 pounds of hydrated lime per pound (5.4 kg/kg) of ammonia-nitrogen will be required to maintain the pH. Sufficient alkalinity should be provided to leave a residual of 30 to 50 mg/*L* after complete nitrification.

3. Temperature

The optimum wastewater temperature range is between 60 to 95 degrees F (15 to 35°C) for good nitrification operation. Nitrification is inhibited at low wastewater temperatures and up to five times as much detention time may be needed to accomplish "complete nitrification" in the winter as is needed in the summer. The growth rate of nitrifying bacteria increases as the wastewater temperature increases and conversely it decreases as the wastewater temperature decreases. Since there is no control over the wastewater temperature, operating compensations for slower winter growth rates are necessary. Increasing the MLVSS concentration, the MCRT, and adjusting the pH to favorable levels can be expected to provide substantial, if not "complete," oxidation of ammonia-nitrogen compounds. Under summer conditions, operation will be possible at less favorable pH levels and lower MLVSS concentrations.

4. Nitrogenous Food

The growth rate of nitrifying bacteria (nitrosomonas and nitrobacter) is affected very little by the organic load applied to the aeration system. However, the population of the nitrifying bacteria will be limited by the amount of nitrogenous food available in the wastewater. Organic nitrogen and phosphorus-containing compounds as well as many trace elements are essential to the growth of microorganisms in the aeration system. The generally recommended ratio of five-day BOD to nitrogen to phosphorus for domestic waste is 100:5:1. Laboratory nitrogen determination (TKN) and phosphorus determination analysis should be performed so that you may add the supplemental phosphorus nutrient if necessary. Phosphorus in the form of phosphate fertilizer may be added and adjusted according to the five-day BOD level and the TKN concentration in the wastewater.

5. Detention Time

The time required for nitrification is directly proportional to the amount of nitrifiers present in the system. Because the rate of oxidation of ammonia-nitrogen is essentially linear or constant, short-circuiting must be prevented. The aeration tank configuration should insure that flow through the tank follows the plug-flow mixing model as closely as possible and provides a minimum detention time of approximately 4.0 hours. Single-pass tanks may be modified and divided into a series of three compartments with ports between them to preclude short-circuiting. Not all of the various modifications to the activated sludge process are appropriate for nitrification applications, although some see use only where partial ammonia removal is required.

6. MCRT, F/M, or Sludge Age

To achieve the desired degree of nitrification, the MCRT must be long enough (usually 4 days plus) to allow the nitrifying bacteria sufficient time to grow. Since the nitrifying bacteria grow much more slowly than the bacteria using the carbonaceous compounds, it is possible to waste the nitrifying bacteria from the system at a higher rate than their growth rate. In simpler terms, this means that nitrification in plants can be maintained only when the rate of growth of nitrifying bacteria is rapid enough to replace organisms lost through sludge wasting. When these bacteria can no longer keep pace, the ability to nitrify decreases and may stop.

When reviewing the performance of your activated sludge process for the selection of an optimum F/M ratio, MCRT or sludge age, oxygen requirements for bacteria using the carbonaceous compounds should be considered along with nitrification requirements. These guidelines should be selected to provide the degree of nitrification required by the discharge permit. If the ammonia-nitrogen limit is being exceeded, the MCRT or sludge age should be increased. Increasing these guidelines will increase the MLVSS and consequently decrease the F/M ratio. With the other conditions (discussed above) constant, a definite relationship will exist between the weight ratio of the ammonia-nitrogen oxidized per day to the MLVSS under aeration.

The growth of cell mass from the oxidation of ammonia is about 0.05 lbs per lb (0.05 kg/kg) of ammonia-nitrogen oxidized. As a result, the degree of nitrification will have little effect on the net sludge yield and WAS rates.

7. Toxic Materials

Various types of toxic materials which will inhibit the nitrification process (in concentrations greater than those indicated) are shown below.

a. Halogen-substituted phenolic compounds, 0.0 mg/*L*.

b. Thiorea and thiorea derivatives, 0.0 mg/*L*.

c. Halogenated solvents, 0.0 mg/*L*.

d. Heavy metals, 10 to 20 mg/*L*.

e. Cyanides and all compounds from which hydrocyanic acid is liberated on acidification, 1 to 2 mg/*L*.

f. Phenol and cresol, 20 mg/*L*.

Pretreatment alternatives provide a degree of removal of the toxicants present in raw wastewater. However, the types of toxicants removed by each pretreatment stage vary among the alternatives. Chemical primary treatment can be used where toxicity from heavy metals is the major problem. Lime primary treatment is one of the most effective processes for removal of a wide range of metals. Chemical treatment is usually not effective for removal of organic toxicants, unless it is coupled with a carbon adsorption step such as in a physical-chemical treatment sequence.

When materials toxic to nitrifiers are present in the raw wastewater on a regular basis, the pretreatment technique most suitable for their removal can be used in the plant to safeguard the nitrifying population. The determination of the most suitable pretreatment process application may be initially developed based on *BENCH SCALE ANALYSIS*[16] to screen alternatives.

The particular pretreatment technique that is effective may also indicate the type of toxicant that is interferring with nitrification and may permit identification and elimination of the source. Subsequent specific analysis can then be run in the identified category of compounds. If the toxicants cannot be eliminated by a source control program, often a pilot study of the process identified by the bench scale tests can be justified to confirm the process selection.

2.64 Rising Sludge and the Nitrification Process

Rising sludge caused by unwanted denitrification in the clarifiers may occasionally plague your nitrification operation. Denitrification occurs because the facultative heterotrophic organisms in the biological sludge in the clarifier accomplish nitrate reduction by what is known as a process of nitrate dissimilation. In this process, nitrate and nitrite replace oxygen in the respiratory process of the organisms under oxygen-deficient conditions. This nitrate dissimilation allows bubbles of nitrogen gas and carbon dioxide to adhere to the sludge floc surface resulting in rising sludge.

The degree of stabilization of the sludge in the aeration tank (depending on detention time and DO) also has a profound effect on denitrification in the clarifier. Clarifier sludges containing partially oxidized or unoxidized organics float more readily than well oxidized sludges. Wastewater temperature is also important as it affects the rate of denitrification and therefore affects the rate of gas and bubble formation (depends on warm temperatures and denitrification rates).

Some considerations for good clarifier operation to preclude denitrification in the clarifier are discussed in the following sections.

1. The settled sludge must be quickly removed from the clarifier to minimize the occurrence and duration of oxygen-deficient conditions. The RAS rate may be proportioned with the aerator influent flow to maintain an essentially "zero" sludge blanket in the clarifier.
2. Since the nitrification sludge is lighter and does not compact as well as carbonaceous sludges, sludges with low SVI values are preferable. They can be withdrawn from the clarifier faster. Since the saturation level of nitrogen is greater in deep tanks than laboratory cylinders, bubbles will form and sludges will float faster in the laboratory than in the field.
3. There is a minimum concentration of nitrate-nitrogen below which there is insufficient nitrogen to cause rising sludge. In weak wastewaters or for those plants in which nitrification is suppressed, rising sludge will not occur.
4. A drop in wastewater temperature will reduce denitrification rates and may render rising sludge a problem only under warmer wastewater conditions.

2.65 Acknowledgments

Major portions of Section 2.6 were taken from *PROCESS CONTROL MANUAL FOR AEROBIC BIOLOGICAL WASTEWATER TREATMENT FACILITIES*, Municipal Operations Branch, Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C. 20460, *NITRIFICATION AND DENITRIFICATION FACILITIES, WASTEWATER TREATMENT*, EPA Technology Transfer Publication, U.S. Environmental Protection Agency, center for Environmental Research Information, 26 West St. Clair Street, Cincinnati, Ohio 45268, and *PROCESS DESIGN MANUAL, NITROGEN CONTROL*, U.S. Environmental Protection Agency, Center for Environmental Research Information, 26 West St. Clair Street, Cincinnati, Ohio 45268.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 111.

2.6A List the harmful effects that could result from the discharge of nitrogenous compounds from wastewater treatment plants.

2.6B What are the principal control guidelines for biological nitrification?

2.6C How can you control rising sludge that results from unwanted denitrification?

2.7 REVIEW OF PLANS AND SPECIFICATIONS — PURE OXYGEN ACTIVATED SLUDGE SYSTEMS

2.70 Need to be Familiar with System

The operational staff that reviews the plans and specifications for a pure oxygen plant should be very familiar with the activated sludge process. A tour through an existing pure oxygen system would be extremely helpful. Specific questions regarding the operation and maintenance of the facility can be answered by manufacturers or other treatment plant personnel whose systems use pure oxygen. Also, sources of industrial waste discharges should be identified and investigated for possible toxic wastes, heavy load contributions, and seasonal fluctuations. Be sure your plant has the capacity and flexibility to treat all industrial wastes.

After plans are submitted, the operation and maintenance staff should review all areas of the plans and specifications with special attention directed towards:

1. Physical plant layout,
2. Oxygen generation equipment,
3. Reactor basins (aeration tanks),
4. Oxygen safety and process instrumentation, and
5. Preventive maintenance program.

2.71 Physical Layout

The pure oxygen generation system should be located near the plant maintenance facilities. If this is not possible, an area within the system should be included. This will be an aid during major maintenance on the facility. Major pieces of equipment should be easily accessible. A crane or other lifting devices should be provided to lift large pieces of equipment during major overhauls. Road access and loading facilities should also be provided. Sources of noise and vibrations should also be considered. Most equipment in oxygen production systems produce noise similar to air blower systems and, if not properly installed, could produce vibrations which could be transferred through walls or structures adjacent to such facilities. In offices or laboratories, noise considerations should also be reviewed, especially in plants where housing areas are near the oxygen generation site. Silencers are typically provided with the generation equipment. The overall layout of the system should also allow for expansion of the wastewater treatment plant and oxygen production facilities.

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[16] *Bench scale analysis. A method of studying different ways of treating wastewater and solids on a small scale in a laboratory.*

2.72 Oxygen Generation Equipment

If the oxygen generation equipment is located within a building, it should be well ventilated. In areas of extremely hot temperatures, vent fans on the roof would be of benefit. A heating system is normally not required if the lowest temperature does not remain below freezing for long periods of time. The compressor equipment generates sufficient heat which can heat the building. Systems located in the open must be designed to operate during the most severe weather conditions.

Individual equipment suppliers recommended by the design engineer should be contacted for specific answers to the installation of compressors, valve skids or oxygen storage facilities. Start-up controls, instrumentation, and safety devices should be carefully reviewed. A vibration shutdown system on compressors should be included. Prior to actual start-up, the manufacturer should run each compressor and check the equipment for proper operation, including excessive vibration. When everything operates in an acceptable manner, calibrate and set vibration monitor to shut down the equipment if excessive vibration develops. This monitor insures proper operation and protection of the equipment. If a separate water cooling system is provided, the water used should be treated to avoid scaling and corrosion of the units.

A specific cleaning requirement should be specified in the plans and specs which would include oxygen pipe lines, sample lines, valve skids and other equipment to insure equipment protection during start-up. Contamination from dirt, grease, and welding slag should never be allowed in a pure oxygen atmosphere. The specifications should include a requirement that equipment manufacturers be present during the start-up and provide a training program to the operations staff. A recommended spare parts list and source of suppliers or vendors should be provided.

Major oxygen feed lines, valves, sample tubing and electrical systems must be tagged and indicated in the "as built" drawings and instruction booklets. Specialized drawings and instruction booklets must include detailed descriptions on preventive maintenance, safety and operation instructions. At least four (4) copies should be provided. Any modification during start-up should be indicated in these manuals.

2.73 Reactors (Aeration Tanks)

The location of the reactor should be reviewed with consideration for future expansion. Reactors located above normal ground elevation should have facilities provided to remove equipment located on the deck. Oxygen reactors are usually completely covered and access to each basin must be provided through a sealed and air-tight lid or locking manhole. Gas sampling lines or other conduits can be installed within the deck. If they are located on the deck, they should be protected and indicated by safety signs to avoid a tripping hazard.

The deck should be a rough surface such as broomed concrete. A completely smooth deck is a slipping hazard if water is allowed to collect. Warning signs should be provided at each entrance to indicate the presence of oxygen and that no smoking or open flames are allowed. A well lighted deck is helpful for night shift operators.

Interior metal such as weir plates, mixer blades and valves should be constructed of stainless steel, carbon steel, or coated carbon steel as dictated by the specific service. A good protective coating should also be provided over any surfaces that may corrode. Control valves should have position indicators and be located in such a manner that preventive maintenance may be performed without draining the reactor. Equipment on the reactor should be tagged with equipment numbers corresponding to electrical control panel facilities.

2.74 Safety and Instrumentation

Operator safety and process safety are both very important in pure oxygen systems. Safety signs, belt guards, temperature shutdown switches and overload protection devices should be provided and indicated in the specifications by the engineer. A system "emergency trip switch" station should be provided and located away from major electrical controls. If tripped during a major mechanical or electrical equipment failure, the entire oxygen operation shuts down without endangering personnel or equipment.

The specifications should include a requirement that the equipment supplier provide a training class to instruct personnel on operation, maintenance, and safety hazards involved in the pure oxygen generation and waste treatment process. Process control involves major instrumentation and control systems. Preventive maintenance on such systems is extremely technical in nature and should be completely understood before maintenance personnel attempt to maintain such systems. The design engineer can provide the necessary background to ensure proper training.

One major area of concern is instrumentation sample tubing and heat trace lines. These systems are the main control and safety equipment functions of the entire system. To avoid costly errors, the manufacturer or equipment supplier should be consulted. If sample lines for lower explosive limit (L.E.L.) or system pressure sensing control lines are incorrectly installed, the entire operation could fail. If they must be installed under roadways, they should be protected within rigid, sealed conduit to prevent being crushed or kinked.

2.75 Preventive Maintenance

Most specifications would not include specific requirements for preventive maintenance. The system design should give consideration to the staff size and experience needs of the system. The design engineer could direct key personnel towards the needs of the system and requirements. Manufacturers can provide maintenance contracts which provide preventive maintenance as well as major tune-ups. Spare parts can be included but can be purchased separately. The cost of such contracts depends on the needs of the system and the options involved.

End of Lesson 4 of 4 Lessons
on
ACTIVATED SLUDGE

Please work the discussion and review questions next.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 4 of 4 Lessons)

Chapter 2. ACTIVATED SLUDGE

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 3.

15. Why would an operator want to monitor the influent to a wastewater treatment plant?
16. How can undesirable constituents be detected in a plant influent in addition to the use of automatic monitoring units?
17. Why should an operational strategy be developed before a toxic waste is discovered in the influent to a plant?
18. Why do some industries pretreat industrial process wastewaters?
19. Why does the operator of an industrial waste treatment plant have to know the flow and waste characteristics of the wastewater being treated?
20. How do toxic materials enter the waste stream?
21. Why should grit, soil, grease and oil be removed from the waste stream?
22. How can the amount of nutrients to be added each day be determined?
23. How does ammonia stripping remove nitrogen from wastewater?
24. How is the nitrification process influenced by temperature?
25. How would you handle materials toxic to a nitrification process?

Please work the objective test next.

PLUS
TIMES
MINUS

SUGGESTED ANSWERS

Chapter 2. ACTIVATED SLUDGE

Pure Oxygen Plants and Operational Control Options

Answers to questions on page 43.

2.0A Pure oxygen systems dissolve oxygen with a higher efficiency for use by microorganisms treating the wastes. This allows the use of smaller reactor tanks than air activated sludge tanks. The sludge produced has improved settleability and dewaterability.

2.0B Biological nitrification can remove ammonia from wastewater by converting it to nitrate.

Answers to questions on page 47.

2.1A Pure oxygen reactors are staged to increase the efficiency of the use of oxygen.

2.1B As the pure oxygen flows from one stage to the next stage, the oxygen is diluted by the carbon dioxide produced by the microorganisms and the nitrogen stripped from the wastewater being treated.

Answers to questions on page 50.

2.1C The two methods commonly used to produce pure oxygen are:

1. Pressure Swing Adsorption (PSA) Oxygen Generating System;
   and
2. Cryogenic Air Separation Method.

2.1D Cryogenics means very low temperature.

2.1E Cryogenic plants are usually shut down once a year for approximately five to seven days for maintenance.

Answers to questions on page 52.

2.1F Special measurements used to control pure oxygen systems include:

1. Reactor vent gas;
2. Reactor gas space pressure; and
3. Dissolved oxygen.

2.1G Hydrocarbons can be detected before they reach the reactor by installing an L.E.L. detector in the plant headworks.

END OF ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 55.

2.2A
1. MLSS, **M**ixed **L**iquor **S**uspended **S**olids.
2. MLVSS, **M**ixed **L**iquor **V**olatile **S**uspended **S**olids.
3. RAS, **R**eturn **A**ctivated **S**ludge.
4. F/M, **F**ood to **M**icroorganism Ratio.

2.2B The two basic approaches that can be used to control the RAS flow rate are:

1. Controlling the RAS flow rate independently from the influent flow; and
2. Controlling the RAS flow rate as a constant percentage of influent flow.

Answers to questions on page 55.

2.2C The sludge blanket depth should be kept to one to three feet (0.3 to 1 m) as measured from the clarifier bottom at the sidewall.

2.2D The sludge blanket depth should be measured at the same time every day during the period of maximum flow and high solids loading rate so the depth will be measured under the same conditions of flow and solids loading.

Answers to questions on page 58.

2.2E Techniques used to determine the rate of RAS flow include:

1. Monitoring the depth of the sludge blanket;
2. Settleability approach; and
3. SVI approach.

2.2F Sludge is allowed to settle 30 minutes in the settleability test.

2.2G

Known		**Unknown**
Infl. Flow, MGD	= 4 MGD	RAS Flow, MGD
Sl. Set. Vol (SV), ml/*L*	= 250 ml/*L*	

1. Calculate RAS flow as a percent of influent flow.

$$\text{RAS Flow, \%} = \frac{\text{SV, ml}/L \times 100\%}{1{,}000\ \text{ml}/L - \text{SV, ml}/L}$$

$$= \frac{250\ \text{ml}/L \times 100\%}{1{,}000\ \text{ml}/L - 250\ \text{ml}/L}$$

$$= \frac{250\ \text{ml}/L \times 100\%}{750\ \text{ml}/L}$$

= 33% of influent flow rate

2. Calculate RAS flow, MGD.

$$\text{RAS Flow, MGD} = \text{RAS Flow, decimal} \times \text{Infl. Flow, MGD}$$
$$= 0.33 \times 4 \text{ MGD}$$
$$= 1.33 \text{ MGD}$$

End of answers to questions in lesson 2

Answers to questions on page 61.

2.3A The objective of wasting activated sludge is to maintain a balance between the microorganisms and the amount of food as measured by the COD or BOD test.

2.3B Wasting of the excess activated sludge is usually achieved by removing a portion of the RAS flow. Sometimes wasting is directly from the MLSS in the aeration tank.

2.3C

Known		Unknown
Solids Added, lbs/day	= 4,750 lbs/day	WAS Flow, MGD and GPM
Solids Aerated, lbs	= 41,100 lbs	
RAS Susp. Sol., mg/*L*	= 5,800 mg/*L*	
Desired Sludge Age, days	= 8 days	

1. Calculate the desired solids under aeration for the desired sludge age of 8 days.

$$\text{Desired Solids, lbs} = \text{Solids Added, lbs/day} \times \text{Sludge Age, days}$$
$$= 4{,}750 \text{ lbs/day} \times 8 \text{ days}$$
$$= 38{,}000 \text{ lbs}$$

2. Calculate the WAS flow, MGD and GPM to maintain the desired sludge age.

$$\text{WAS Flow, MGD} = \frac{\text{Solids Aerated, lbs} - \text{Desired Solids, lbs}^{*}}{\text{RAS Susp. Sol., mg/}L \times 8.34 \text{ lbs/gal}}$$
$$= \frac{(41{,}100 \text{ lbs} - 38{,}000 \text{ lbs})/\text{day}}{5{,}800 \text{ mg/}L \times 8.34 \text{ lbs/gal}}$$
$$= 0.064 \text{ MGD} \times 694 \text{ GPM/MGD}$$
$$= 45 \text{ GPM}$$

* Difference represents solids wasted in pounds per day.

Answers to questions on page 64.

2.3D Four facts that should be remembered regarding the F/M method of control.

1. The food concentration is estimated by the COD or BOD tests.
2. The amount of food (COD or BOD) applied is important to calculate the F/M.
3. The quantity of microorganisms can be represented by the quantity of MLVSS.
4. The data obtained to calculate the F/M should be based on the seven-day moving average.

2.3E

Known		Unknown
F/M, $\frac{\text{lbs COD/day}}{\text{lb MLVSS}}$	$= \frac{0.30 \text{ lbs COD/day}}{\text{lb MLVSS}}$	MLSS, lbs
COD added, lbs/day	= 7,000 lbs COD/day	
Volatile portion	= 0.70	

1. Determine the desired pounds of MLVSS.

$$\text{Desired MLVSS, lbs} = \frac{\text{COD applied, lbs/day}}{\text{F/M, lbs COD/day/lb MLVSS}}$$
$$= \frac{7{,}000 \text{ lbs COD/day}}{0.30 \text{ lbs COD/day/lb MLVSS}}$$
$$= 23{,}333 \text{ lbs MLVSS}$$

2. Determine the desired lbs MLSS.

$$\text{Desired MLSS, lbs} = \frac{\text{Desired MLVSS, lbs}}{\text{MLSS VM portion}}$$
$$= \frac{23{,}333 \text{ lbs MLVSS}}{0.70}$$
$$= 33{,}333 \text{ lbs}$$

2.3F The MCRT expresses the average time a microorganism spends in the activated sludge process.

Answers to questions on page 68.

2.3G The microorganisms that are important indicators in the activated sludge process are the protozoa and rotifers.

2.3H Important activated sludge control tests that are used to define sludge quality and process status include final clarifier sludge blanket depth, mixed liquor and return sludge concentrations, and sludge settleability.

END OF ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 72.

2.4A An industrial waste monitoring program is valuable for the operator of an activated sludge plant for the following reasons:

1. To maintain sufficient control of treatment plant operations to prevent NPDES permit violations; and
2. To gather necessary data for the future design and operation of the treatment plant.

2.4B Common wastewater monitoring devices include:

1. Flow measuring;
2. pH monitoring;
3. Oxidation potential monitoring;
4. Suspended solids monitoring;
5. DO monitoring; and
6. Wastewater samplers.

2.4C If a high organic waste load enters your plant:

1. Gradually increase the RAS flow;
2. Increase the air input to the aeration tanks; and
3. Add nutrients if necessary.

Answers to questions on page 73.

2.50A Types of industries whose wastes could be treated by an activated sludge plant include:

1. Fruit and vegetable processing,
2. Meat and fish processing,
3. Paper product manufacturing, and
4. Petroleum refining.

2.51A The character of industrial wastewater is dependent on the particular production process and the way it is operated.

2.52A One approach to solving a hydraulic overloading problem is to reduce water consumption and minimize waste generation through proper management of processing and production operations.

2.52B The pH of an industrial wastewater can be adjusted (1) upwards by the addition of caustic, and (2) downwards by the addition of sulfuric acid.

2.52C Chemical oxidation (COD) measures the presence of (1) *CARBON* and (2) *HYDROGEN*, but not (3) *AMINO NITROGEN* in organic materials.

2.52D The three major nutrients are carbonaceous organic matter (measured by BOD test), nitrogen (N) and phosphorus (P). Other elements that might be critical include iron, calcium, magnesium, potassium, cobalt, and molybdenum.

2.52E The most common causes or kinds of toxicity in industrial wastewaters include excessive amounts of free ammonia, residual chlorine, detergents, paints, solvents, and biocides.

Answers to questions on page 74.

2.53A Samples from industrial wastewaters should be collected during each operating shift and during different stages of the finished-product and raw-product runs.

2.53B Large variations in flow can be reduced or smoothed out by routing the flows through a surge or storage tank.

2.53C Discrete waste solids (such as trimmings, rejects, corn meal and pulp) are effectively separated from the wastewater flow by various types of screens.

2.53D Screens should be located as close as possible to the process/production producing the waste. The longer the solids are in contact with water and the rougher the flow is handled (more turbulent), the more material will pass through the screens and the more the solids will become dissolved.

Answers to questions on page 77.

2.53E Generally the most economical location to treat toxic wastes is at the source. If possible, do not allow toxic wastes to enter the plant wastewater.

2.53F Industrial waste pretreatment facilities are necessary to treat industrial wastes so they can be treated by the activated sludge process. Pretreatment involves pH adjustment, coarse solids removal, flow equalization, nutrient addition and cooling.

2.53G Screens are used to remove coarse solids to reduce unnecessary clogging and wear on downstream pipes, pumps, aerators and clarifier mechanisms. Also this process will help avoid odor problems that could develop from the settling out of solids in the equalization and emergency basins.

2.53H Organic loadings can be smoothed out by the use of an equalizing tank and also by keeping the contents of the tank well mixed.

2.53I Nitrogen is supplied in the form of ammonia (usually as 30 percent aqueous) and phosphorus as phosphoric acid (usually as 75 percent aqueous).

2.53J "Seed activated sludge" may be obtained from either a nearby municipal or industrial wastewater treatment plant.

2.53K Initially industrial wastes must be added gradually to the aeration basin to allow time for the activated sludge microorganisms to adapt or become acclimated to the wastes.

Answers to questions on page 78.

2.54A Nutrients should be added to wastewater at a point where the incoming wastewater is highly mixed and preferably in the aeration basin.

2.54B Supplemental nitrogen can be provided by aqueous ammonia or anhydrous ammonia. Supplemental phosphorus can be provided by dissolved triple superphosphate, phosphate fertilizer, or phosphoric acid.

2.54C Factors or conditions that have been found to cause the disappearance of higher forms of microorganisms from the activated sludge process include:

1. DO levels below 3 to 4 mg/*L*,
2. High organic loadings,
3. Toxic substances or nutrient deficiencies, and
4. pH control.

2.54D A gradual decrease in percent solids removal from an activated sludge process over a period of time may be the result of grit and silt accumulation in the aeration basin which was not carried out in the effluent and remained in the basin, thus resulting in reduced aeration volume and detention time.

Answers to questions on page 85.

2.55A Accurate records must be kept for the following reasons:

1. To help troubleshoot problems which arise,
2. To account for the operation of the plant during appropriate times, and
3. To serve as legal documents which will protect the company from unjust claims.

2.55B Effluent from a pulp and paper mill activated sludge process should contain some nutrients. If low levels of nutrients are present, a nutrient deficiency could exist in the process.

2.55C The paper industry might shut down an activated sludge process during holidays, maintenance (preventive and emergency), process upsets, strikes, and scheduled production reductions.

2.55D The periodic feeding (step-feed) technique for process start-up of activated sludge systems is effective because it allows organisms time to consume the available food (waste). When they are ready for more food, more is added. This procedure encourages rapid microorganism reproduction.

Answers to questions on page 95.

2.56A Primary clarifiers are not very effective in removing BOD because most of the BOD is "soluble" or "dissolved" and can't be removed by sedimentation.

2.56B Nutrients can be metered into the primary clarifier effluent. To supplement nitrogen, ammonia gas (or liquid) can be added. Phosphoric acid (H_3PO_4) can be used as a source of phosphorus. Sufficient phosphorus may be present in the influent from malting by-products and phosphorus based cleaning solutions.

2.56C The MLSS level in aeration basins is influenced by:

1. Influent organic loading, and
2. Temperature.

2.56D The sludge wasting rate is adjusted in an attempt to regulate the actual MLSS in the aeration basins as close as practical to the desired MLSS "set point."

2.56E Filamentous "bulking" can be controlled by:

1. Proper DO levels in aeration basins,
2. Providing sufficient nutrients (nitrogen and phosphorus) and trace minerals,
3. Proper F/M ratios, and
4. Minimizing large fluctuations or influent organic loadings.

Answers to questions on page 99.

2.57A High strength artichoke waste influents (BOD > 6,000 mg/*L*) are diluted with medium strength wastewater to produce an influent BOD of less than 6,000 mg/*L* before treatment by the activated sludge process.

2.57B Fifteen-day moving averages were computed and plotted for artichoke influent COD and F/M ratio to reduce the effect of fluctuating daily results.

2.57C Ammonium phosphate can be used to provide both nitrogen and phosphorus for the treatment of artichoke wastes.

2.57D If domestic or sanitary wastes are not treated by a dairy waste treatment plant, effluent chlorination may not be necessary.

2.57E High levels of MLSS are necessary to prevent process upsets caused by shock organic loadings.

Answers to questions on page 101.

2.58A The three main petroleum refinery waste compounds that can be treated by the activated sludge process are ammonia, phenols, and sulfide.

2.58B MCRTs as high as 30 days are necessary to treat petroleum refinery wastes in order to maintain the nitrification population necessary to oxidize ammonia.

2.58C A shock load of phenols can be treated by decreasing the hydraulic loading. Hydrogen peroxide can be used to help oxidize phenols in the effluent.

Answers to questions on page 105.

2.6A Harmful effects that could result from the discharge of nitrogenous compounds include:

1. Ammonia toxicity to fish life,
2. Reduction in effectiveness of chlorine disinfection efficiency,
3. Increase in DO depletion of receiving waters,
4. Adverse public health impact on ground water, and
5. Reduction of suitability of water for reuse.

2.6B The principal control guidelines for biological nitrification are:

1. DO,
2. pH,
3. Wastewater temperature,
4. Nitrogenous food,
5. Detention time,
6. MCRT, F/M or sludge age, and
7. Toxic materials.

2.6C Rising sludge resulting from unwanted denitrification can be controlled by:

1. Returning settled sludge as quickly as possible and maintaining essentially "zero" sludge blanket in the clarifier; and
2. Maintain sludges with low SVI values.

END OF ANSWERS TO QUESTIONS IN LESSON 4

OBJECTIVE TEST

Chapter 2. ACTIVATED SLUDGE

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1, Volume I, *OPERATION OF WASTEWATER TREATMENT PLANTS*. There may be more than one correct answer to each question.

1. As oxygen rises through the mixed liquor to the surface of a reactor, most of the oxygen is absorbed into the mixed liquor.
   1. True
   2. False

2. Pure oxygen systems may be used to supply oxygen to any of the activated sludge process modes — conventional, step feed, complete mix or contact stabilization.
   1. True
   2. False

3. Operation of the secondary clarifiers, return sludge rates, and wasting rates are much the same for pure oxygen systems as they are for conventional air-activated sludge systems.
   1. True
   2. False

4. Monitoring the depth of the sludge blanket in the clarifier is the most direct method available for determining the RAS flow rate.
   1. True
   2. False

5. A limitation of using the constant flow RAS approach is that the F/M ratio remains constant.
   1. True
   2. False

6. The objective of wasting activated sludge is to maintain a balance between the microorganisms under aeration and the amount of incoming food.
   1. True
   2. False

7. Wasting of activated sludge must be accomplished on a continuous basis.
   1. True
   2. False

8. The character (constituent) of industrial wastewaters depends on the particular production process and the way the process is operated.
   1. True
   2. False

9. All nutrients need to be in a soluble form to be used by the microorganisms in a biological treatment process.
   1. True
   2. False

10. An advantage of biological treatment processes is that the microorganisms can easily adjust to great fluctuations of flows and wastes (BOD).
    1. True
    2. False

11. When should the oxygen vent valve on the last reactor be opened?
    1. When the combined carbon dioxide and nitrogen concentrations reach an excess of 55 percent for an extended period
    2. When the Lower Explosive Limit (L.E.L.) is above 20 percent
    3. When the methane concentration is above 65 percent
    4. When the oxygen concentration drops below 45 percent for an extended period
    5. When the oxygen concentration drops below 75 percent for an extended period.

12. How is oxygen provided to the reactor while a cryogenic unit is shut down for maintenance?
    1. By a standby cryogenic unit
    2. By another parallel cryogenic unit
    3. By surface aerators
    4. By the use of liquid oxygen from storage tanks
    5. By using algae to produce oxygen by photosynthesis

13. Methods use to determine the RAS flow rate include
    1. Mixed liquor volatile suspended solids approach.
    2. Monitoring the depth of the sludge blanket.
    3. Organic loading.
    4. SVI approach.
    5. Settleability approach.

14. How can the sludge blanket depth be measured in the secondary clarifier?
    1. By looking over side of clarifier and reading depth markings on wall
    2. By lowering a surveyor's rod until the end disappears in the blanket
    3. By using a sight glass finder
    4. By using an electronic sludge level detector
    5. By using sonar

15. The amount of waste activated sludge (WAS) removed from the process affects which of the following items?
    1. Effluent quality
    2. Growth rate of microorganisms
    3. Mixed liquor settleability
    4. Occurrence of foaming/frothing
    5. Oxygen consumption

16. When activated sludge is wasted on a continuous basis, the operator should check the return activated sludge volatile suspended solids at least
    1. Every two hours.
    2. Every four hours.
    3. Once every shift.
    4. Every other day.
    5. Once a week.

17. Why do industries pretreat wastewaters before discharging to the collection system?
    1. To impress the public
    2. To keep undesirable constituents out of the sewers
    3. To recover valuable materials
    4. To reduce sewer-service charges
    5. To train operators

18. What types of industrial wastes could inhibit the activity of microorganisms in a treatment plant?
    1. Heavy metals
    2. Low pH wastewaters
    3. Methanol
    4. Organic materials
    5. Toxic wastes

19. How can a toxic waste be discovered in a treatment plant?
    1. Decrease in aerator DO
    2. Decrease in secondary effluent floc
    3. Increase in aerator DO
    4. Increase in plant inflow
    5. Increase in secondary effluent floc

20. The primary disadvantage of the COD test is its susceptability to interference by
    1. Amino nitrogen.
    2. Borate.
    3. Chloride.
    4. Iron.
    5. Sulfide.

21. How can ammonia nitrogen be removed from wastewater?
    1. Ammonia stripping
    2. Biological nitrification
    3. Breakpoint chlorination
    4. Ion exchange
    5. Pressure filtration

22. What is the minimum recommended DO in an aeration tank for biological nitrification?
    1. 0.5 mg/*L*
    2. 1.0 mg/*L*
    3. 1.5 mg/*L*
    4. 2.0 mg/*L*
    5. 4.0 mg/*L*

23. How does breakpoint chlorination remove ammonia?
    1. By breaking down ammonia
    2. By oxidizing ammonia-nitrogen to nitrogen gas
    3. By producing alkalinity conditions
    4. By removing the nitrifying bacteria
    5. By using up the oxygen

24. Procedures used for shutdown and subsequent start-up of activated sludge processes treating industrial wastes vary with the
    1. Crew available for shutdown.
    2. Duration of shutdown.
    3. Microorganisms (MLVSS) in aeration basin.
    4. Nature of shutdown.
    5. Weather expected during shutdown.

25. Important objectives that should be accomplished during shut-downs and start-ups include
    1. Conform with legal requirements (NPDES Permit) for plant effluent.
    2. Delay subsequent start-up as long as possible.
    3. Maintain satisfactory process performance.
    4. No personal injuries.
    5. Treat wastes at a minimum cost for satisfactory performance.

26. Possible techniques for controlling filamentous organisms in an industrial activated sludge process include
    1. Dosage of return sludge with oxidants such as hydrogen peroxide or chlorine.
    2. Lower DO levels in aeration basins so filamentous organisms cannot breathe or respire.
    3. Lower F/M level to starve filamentous organisms.
    4. Reduce nutrients essential for filamentous growth.
    5. Stop sludge wasting to allow activated sludge organisms to gain control.

27. Petroleum refinery wastes that can be treated by the activated sludge process include
    1. Ammonia
    2. Chloride
    3. Iron
    4. Phenols
    5. Sulfide

28. What is the return activated sludge (RAS) flow in GPM when the influent flow is 2 MGD, the mixed liquor suspended solids (MLSS) are 2,200 mg/*L*, and the RAS suspended solids are 8,100 mg/*L*?
    1. 0.55 GPM
    2. 0.75 GPM
    3. 1.875 GPM
    4. 375 GPM
    5. 520 GPM

29. What is the return activated sludge (RAS) flow in GPM when the influent flow is 2.5 MGD and the sludge settling volume (SV) in 30 minutes is 290 ml/*L*?
    1. 0.725 GPM
    2. 1.025 GPM
    3. 505 GPM
    4. 710 GPM
    5. 1,945 GPM

30. An aeration tank has a volume of 1.4 million gallons. The MLSS is 2,400 mg/*L* and the volatile portion is 0.75. The mixed liquor volatile suspended solids (MLVSS) under aeration is
    1. 17,194 lbs.
    2. 21,017 lbs.
    3. 23,120 lbs.
    4. 28,022 lbs.
    5. 30,940 lbs.

31. Calculate the total waste activated sludge (WAS) flow rate in GPM for a plant that adds 3,560 lbs of solids per day. There are 22,470 lbs of solids in the aerator, the RAS suspended solids concentration is 7,100 mg/*L*, and the current WAS flow is 0.02 MGD. The desired sludge age is 6 days.
    1. 0 GPM, stop wasting
    2. 13 GPM
    3. 15 GPM
    4. 27 GPM
    5. 29 GPM

32. Calculate the desired MLSS if the desired F/M ratio is 0.20 lbs COD/day/lb MLVSS, and if 5,000 lbs of COD per day are added, the volatile portion of the solids in the aeration tank is 0.70 and the tank volume is 1.8 MG.
    1. 2,000 mg/*L*
    2. 2,100 mg/*L*
    3. 2,200 mg/*L*
    4. 2,300 mg/*L*
    5. 2,400 mg/*L*

33. Calculate the ammonia (NH_3-N) that must be added in pounds per day to treat an industrial wastewater. Influent flows are 2.5 MGD and primary effluent TOC is 487 mg/*L* with a BOD:TOC ratio of 2.1:1. Primary effluent NH_3-N concentration is 5.61 mg/*L*. Two pounds of NH_3-N are required for every 100 pounds of BOD treated. Select the closest answer.
    1. 100 lbs NH_3-N/day
    2. 200 lbs NH_3-N/day
    3. 300 lbs NH_3-N/day
    4. 400 lbs NH_3-N/day
    5. 450 lbs NH_3-N/day

END OF OBJECTIVE TEST

CHAPTER 3

SLUDGE HANDLING AND DISPOSAL

by

Liberato D. Tortorici

and

James F. Stahl

(With Special sections by Richard Best and William Anderson)

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OBJECTIVES

Chapter 3. SLUDGE HANDLING AND DISPOSAL

Categories of sludge handling and disposal processes contained in this chapter include thickening, stabilization, conditioning, dewatering, volume reduction and land disposal. Following completion of Chapter 3, you should be able to do the following with regard to the proceses in these sludge handling and disposal categories:

1. Explain the purposes of the processes,
2. Properly start up, operate, shut down, and maintain these processes,
3. Develop operating procedures and strategies for both normal and abnormal operating conditions,
4. Identify potential safety hazards and conduct duties using safe procedures,
5. Troubleshoot when a process does not function properly, and
6. Review plans and specifications for the processes.

GLOSSARY

Chapter 3. SOLIDS HANDLING AND DISPOSAL

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" or dissolved oxygen is *NOT* present in the aquatic environment.

ASPIRATE (ASS-per-RATE) ASPIRATE

Use of a hydraulic device (aspirator or eductor) to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a sump pump.

BAFFLE BAFFLE

A flat board or plate, deflector, guide or similar device constructed or placed in flowing water, wastewater, or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids.

BLIND BLIND

A condition that occurs on the filtering medium of a microscreen or a vacuum filter when the holes or spaces in the media become clogged or sealed off due to a buildup of grease or the material being filtered.

BOUND WATER BOUND WATER

Water contained within the cell mass of sludges or strongly held on the surface of colloidal particles.

BULKING (BULK-ing) BULKING

Clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge becomes too light and will not settle properly.

CAVITATION (CAV-i-TAY-shun) CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller. The collapse of this gas pocket or bubble drives water into the impeller with a terrific force that can cause pitting on the impeller surface.

CENTRATE CENTRATE

The water leaving a centrifuge after most of the solids have been removed.

CENTRIFUGE CENTRIFUGE

A mechanical devicie that uses centrifugal or rotational forces to separate solids from liquids.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining, or filtering.

CONING (CONE-ing) CONING

Development of a cone-shaped flow of liquid, like a whirlpool, through sludge. This can occur in a sludge hopper during sludge withdrawal when the sludge becomes too thick. Part of the sludge remains in place while liquid rather than sludge flows out of the hopper. Also called "coring."

DENITRIFICATION DENITRIFICATION

A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers or gravity thickeners.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid, or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DEWATERABLE DEWATERABLE

This is a property of a sludge related to the ability to separate the liquid portion from the solid, with or without chemical conditioning. A material is considered dewaterable if water will readily drain from it. Generally raw sludge dewatering is more difficult than water removal from digested sludge.

EDUCTOR (e-DUCK-tor) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a suction pump.

ELUTRIATION (e-LOO-tree-A-shun) ELUTRIATION

The washing of digested sludge in plant effluent. The objective is to remove (wash out) fine particulates and/or the alkalinity in sludge. This process reduces the demand for conditioning chemicals and improves settling or filtering characteristics of the solids.

ENDOGENOUS (en-DODGE-en-us) ENDOGENOUS

A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.

FILAMENTOUS ORGANISMS (FILL-a-MEN-tuss) FILAMENTOUS ORGANISMS

Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomyces.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles.

GASIFICATION (GAS-i-fi-KAY-shun) GASIFICATION

The conversion of soluble and suspended organic materials into gas during anaerobic decomposition. In anaerobic sludge digesters, this gas is collected for fuel or disposed of using the waste gas burner.

GROWTH RATE, Y GROWTH RATE, Y

An experimentally determined constant to estimate the unit growth rate of bacteria while degrading organic wastes.

INCINERATION INCINERATION

The conversion of dewatered sludge cake by combustion (burning) to ash, carbon dioxide, and water vapor.

INORGANIC WASTE INORGANIC WASTE

Waste material such as sand, salt, iron, calcium, and other mineral materials which are only slightly affected by the action of organisms. Inorganic wastes are chemical substances of mineral origin; whereas organic wastes are chemical substances usually of animal or vegetable origin. Also see NONVOLATILE MATTER.

NITRIFYING BACTERIA NITRIFYING BACTERIA

Bacteria that change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate).

NONVOLATILE MATTER NONVOLATILE MATTER

Material such as sand, salt, iron, calcium, and other mineral materials which are only slightly affected by the action of organisms. Volatile materials are chemical substances usually of animal or vegetable origin. Also see INORGANIC WASTE.

POLYELECTROLYTE (POLY-electro-light) POLYELECTROLYTE

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."

POLYMER (POLY-mer) POLYMER

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often caled a "polyelectrolyte."

POLYSACCHARIDE (polly-SAC-a-ride) POLYSACCHARIDE

A carbohydrate such as starch, insulin or cellulose.

PRECOAT PRECOAT

Application of a free-draining, non-cohesive material such as diatomaceous earth to a filtering media. Precoating reduces the frequency of media washing and facilitates cake discharge.

PROTEINACEOUS (PRO-ten-NAY-shus) PROTEINACEOUS

Materials containing proteins which are organic compounds containing nitrogen.

PUG MILL PUG MILL

A mechanical device with rotating paddles or blades that is used to mix and blend different materials togehter.

PUTRESCIBLE (pew-TRES-uh-bull) PUTRESCIBLE

Material that will decompose under anaerobic conditions and produce nuisance odors.

RABBLING RABBLING

The process of moving or plowing the material inside a furnace by using the center shaft and rabble arms.

RISING SLUDGE RISING SLUDGE

Rising sludge occurs when sludge settles to the bottom of the thickener, is compacted, and then starts to rise to the surface, usually as a result of denitrification.

SCFM SCFM

Cubic Feet of air per Minute at Standard conditions of temperature, pressure, and humidity.

SECONDARY TREATMENT SECONDARY TREATMENT

A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually the process follows primary treatment by sedimentation. The process commonly is a type of biological treatment process followed by secondary clarifiers that allow the solids to settle out of the water being treated.

SEPTICITY (sep-TIS-it-tee) SEPTICITY

Septicity is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or ponds when some of the water or wastewater travels faster than the rest of the flowing water.

SLUDGE-VOLUME RATIO (SVR) SLUGE-VOLUME RATIO (SVR)

The volume of sludge blanket divided by the daily volume of sludge pumped from the thickener.

SLURRY (SLUR-e) SLURRY

A thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles usually have a specific gravity of 0.5 to 2.5.

STABILIZATION STABILIZATION

Conversion to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

THERMOPHILIC BACTERIA (thermo-FILL-lik) THERMOPHILIC BACTERIA

Hot temperature bacteria. A group of bacteria that grow and thrive in temperatures above 113°F (45°C). The optimum temperature range for these bacteria in anaerobic decomposition is 120°F (49°C) to 130°F (57°C).

VECTOR VECTOR

An insect or other organism capable of transmitting germs or other agents of disease.

VOLATILE MATTER (VOL-a-till) VOLATILE MATTER

Matter in water, wastewater, or other liquids that is lost on ignition of the dry solids at 550°C.

Y, GROWTH RATE Y, GROWTH RATE

An experimentally determined constant to estimate the unit growth rate of bacteria while degrading organic wastes.

CHAPTER 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 1 of 5 Lessons)

3.0 NEED FOR SLUDGE HANDLING AND DISPOSAL

3.00 Sludge Types and Characteristics

The solids removed in wastewater treatment plants result in waste streams such as grit, screenings, scum (floatable materials) and sludge (Figure 3.1). Sludge is by far the largest in volume and the handling and disposal of these residual solids represents one of the most challenging problems wastewater treatment plant operators must solve. The problems of dealing with sludge are complicated by the facts that (1) sludge is composed largely of the substances responsible for the offensive character of untreated wastewater, (2) only a small portion of the sludge is solid matter and (3) the response of similar-type sludges to various handling techniques differs from one treatment plant to the next plant. Waste activated sludge (WAS) produces the greatest volume of sludge and sludge disposal problems confronting operators today.

Some general statements can be made about the reaction of similar sludge types to a specific unit process, but the operator should be aware that the exact response of a particular sludge depends on the plant location and on a large number of variables.

This chapter is designed to familiarize the operator with (1) the general characteristics of wastewater treatment plant sludges, (2) the unit processes used to effectively handle sludge, and (3) the operating guidelines necessary for successful unit process performance.

Basically two types of sludge are produced at any *SECONDARY WASTEWATER TREATMENT FACILITY.*[1] They are classified as primary and secondary sludges.

Primary sludge includes all those solids which settle to the bottom of the primary sedimentation tank and are removed from the waste stream. On a very general basis, primary sludge solids are usually fairly coarse and fibrous, have *SPECIFIC GRAVITIES*[2] or *DENSITIES*[3] significantly greater than that of water and are composed of 60 to 80 percent *VOLATILE* (organic) *MATTER.*[4] The remaining 20 to 40 percent of the sludge solids are classified as *NONVOLATILE* (inorganic) *MATTER.*[5]

Secondary sludge is generated as a by-product of biological degradation of organic wastes in the secondary biological (activated sludge and trickling filter) treatment processes. As bacteria feed on and degrade organic matter, new bacteria cells are produced. In order to maintain the desired quantity or population of bacteria within the biological treatment system, some of these new bacteria cells have to be removed from the process stream. Usually these bacteria cells are removed in the secondary clarifier. The biological solids or bacteria cells that are removed are termed secondary sludge. On a very general basis, secondary sludges are more flocculant than primary sludge solids, less fibrous, have specific gravities closer to that of water and consist of 75 to 80 percent volatile (organic) matter and 20 to 25 percent nonvolatile (inorganic) material.

3.01 Sludge Quantities

The daily quantity of primary and secondary sludges removed will vary from one treatment plant to the next plant. Before sludge handling equipment can be designed, purchased and installed, estimates have to be made to determine the daily quantity of sludge removed from the system. Although the design and installation of such equipment is the engineer's responsibility, the operator should be aware of how engineers make these estimates.

3.010 Primary Sludge Production

The quantity of primary sludge generated depends on: (1) the influent wastewater flow, (2) the concentration of influent settleable suspended solids, and (3) the *EFFICIENCY*[6] of the primary sedimentation basin. The estimation of primary sludge production is illustrated in the following example.

EXAMPLE 1. PRIMARY SLUDGE PRODUCTION

Given: The influent flow to a primary clarifier is 1.5 MGD. The influent suspended solids concentration is 350 mg/*L*. The effluent suspended solids concentration from the primary clarifier is 150 mg/*L*.

Find: 1. The total pounds of suspended solids entering the plant per day (lbs SS/day).

---

[1] *Secondary Wastewater Treatment Facility. A wastewater treatment facility used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually the facility follows primary treatment by sedimentation. The facility commonly is a type of biological treatment process followed by secondary clarifiers that allow the solids to settle out of the water being treated.*

[2] *Specific Gravity. Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles usually have a specific gravity of 0.5 to 2.5.*

[3] *Density. A measure of how heavy a substance (solid, liquid, or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.*

[4] *Volatile Matter. Matter in water, wastewater, or other liquids that is lost on ignition of the dry solids at 550°C.*

[5] *Nonvolatile Matter. Material such as sand, salt, iron, calcium and other mineral materials which are only slightly affected by the action of organisms. Volatile materials are chemical substances usually of animal or vegetable origin.*

[6] $$\text{Efficiency, \%} = \frac{(\text{Inf. Susp. Solids, mg/L} - \text{Effl. Susp. Sol., mg/L})\ 100\%}{\text{Infl. Susp. Solids, mg/L}}$$

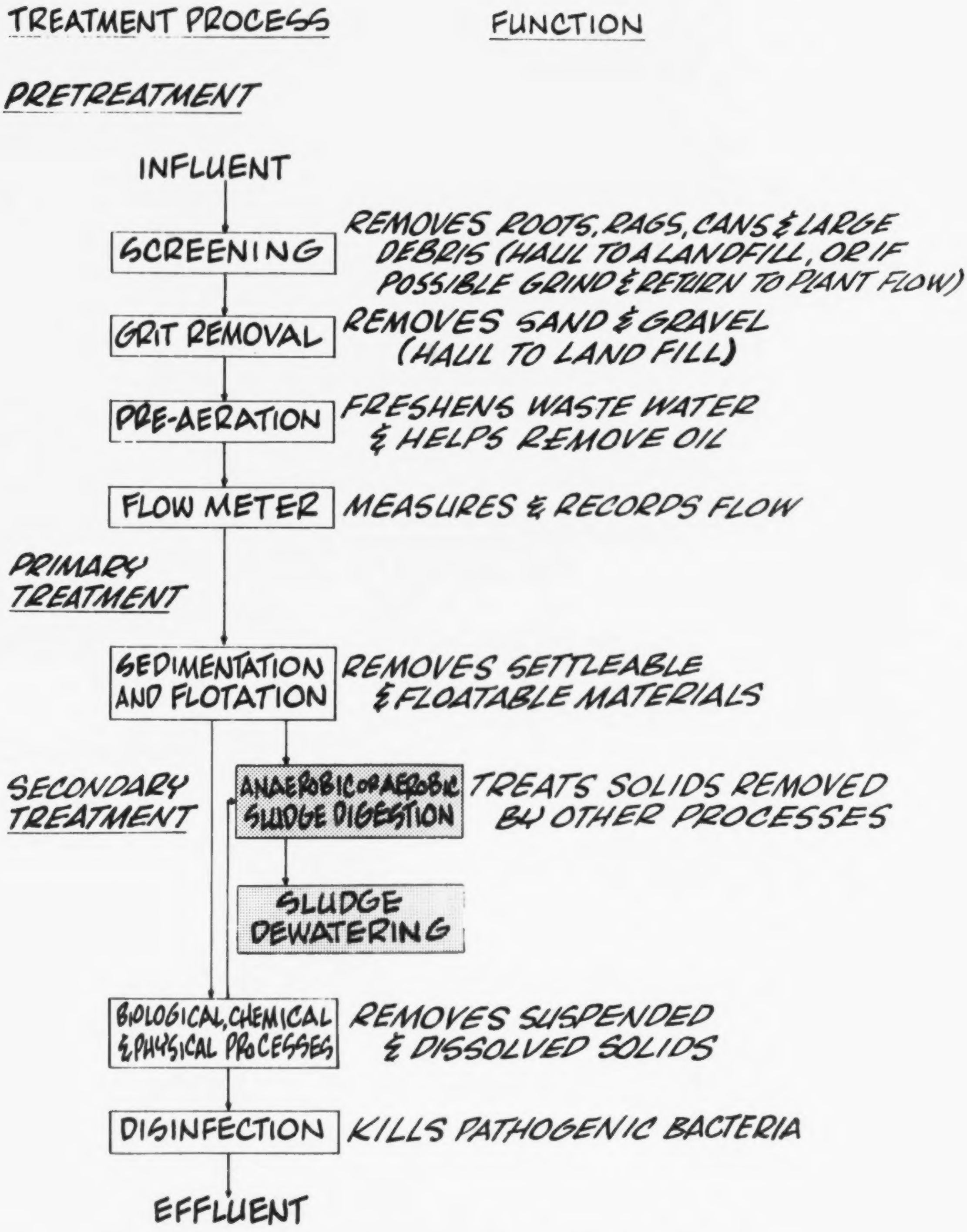
TREATMENT PROCESS
FUNCTION
PRETREATMENT
INFLUENT
SCREENING
REMOVES ROOTS, RAGS, CANS & LARGE DEBRIS (HAUL TO A LANDFILL, OR IF POSSIBLE GRIND & RETURN TO PLANT FLOW)
GRIT REMOVAL
REMOVES SAND & GRAVEL (HAUL TO LAND FILL)
PRE-AERATION
FRESHENS WASTE WATER & HELPS REMOVE OIL
FLOW METER
MEASURES & RECORDS FLOW
PRIMARY TREATMENT
SEDIMENTATION AND FLOTATION
REMOVES SETTLEABLE & FLOATABLE MATERIALS
SECONDARY TREATMENT
ANAEROBIC OR AEROBIC SLUDGE DIGESTION
TREATS SOLIDS REMOVED BY OTHER PROCESSES
SLUDGE DEWATERING
BIOLOGICAL, CHEMICAL & PHYSICAL PROCESSES
REMOVES SUSPENDED & DISSOLVED SOLIDS
DISINFECTION
KILLS PATHOGENIC BACTERIA
EFFLUENT

Fig. 3.1 Typical flow diagram of a wastewater treatment plant

2. The total pounds of suspended solids leaving the primary clarifier with the primary effluent (lbs SS/day).
3. The total pounds of dry (no moisture present) sludge solids produced per day.

Solution:

Known		Unknown
Flow, MGD	= 1.5 MGD	1. Dry SS entering plant, lbs/day
Inf. SS, mg/*L*	= 350 mg/*L*	2. Dry SS leaving primary clarifier, lbs/day
Effl. SS, mg/*L*	= 150 mg/*L*	3. Dry sludge solids produced, lbs/day

1. Calculate the amount of dry influent suspended solids, lbs/day.

Infl Susp Sol, lbs/day = Flow, MGD × Susp Sol, mg/*L* × 8.34 lbs/gal
= 1.5 MGD × 350 mg/*L* × 8.34 lbs/gal
= 4379 lbs/day

2. Calculate the amount of dry suspended solids leaving the primary clarifier, lbs/day.

Prim. Clar. Effl. Susp. Sol, lbs/day = Flow, MGD × Susp Sol, mg/*L* × 8.34 lbs/gal
= 1.5 MGD × 150 mg/*L* × 8.34 lbs/gal
= 1877 lbs/day

3. Calculate the amount of dry primary sludge produced, lbs/day.

Primary Sludge, lbs/day = Inf Susp Sol, lbs/day - Effl Susp Sol, lbs/day
= 4379 lbs/day - 1877 lbs/day
= 2502 lbs/day

OR

Primary Sludge, lbs/day = Flow, MGD × (In SS, mg/*L* - Ef SS, mg/*L*) × 8.34 lbs/day
= 1.5 MGD × (350 mg/*L* - 150 mg/*L*) × 8.34 lbs/gal
= 2502 lbs/day

NOTE: All answers are in terms of pounds of dry solids per day.

3.011 Secondary Sludge Production

The daily quantity of sludge produced is dependent on (1) the influent flow to the biological or secondary system, (2) the influent organic load to the biological system, (3) the efficiency of the biological system in removing organic matter, and (4) the growth rate, Y, of the bacteria within the system. The determination of secondary sludge production is rather complicated due to the mathematics and variables involved. The rate of biological growth, Y, is highly dependent on such variables as temperature, nutrient balances, the amount of oxygen supplied to the system, the ratio between the amount of food supplied (BOD) and the mass or quantity of biological cells developed within the system, detention time and other factors. A detailed discussion of the estimation of growth rates and sludge production is beyond the scope of this chapter. A general rule of thumb that operators may use to estimate secondary sludge production is that for every pound of organic matter (soluble 5-day BOD) used by the bacteria cells, approximately 0.30 to 0.70 pounds of new bacteria cells are produced and have to be taken out of the system. The following example illustrates the estimation of secondary sludge production.

MATHEMATICS
VARIABLES

EXAMPLE 2. SECONDARY SLUDGE PRODUCTION

Given: The primary effluent organic content, as measured by the 5-day BOD test, to a secondary treatment facility is 200 mg/*L*. The secondary effluent 5-day BOD is 30 mg/*L* The bacteria growth rate, Y, is 0.50 lbs SS/lb BOD removed and the flow rate, Q, is 1.5 MGD.

NOTE: The secondary influent flow in your plant may be different than the actual plant effuent flow due to in-plant recycle uses of effluent and/or secondary system streams.

Find:
1. The total pounds of BOD entering the secondary system per day.
2. The total pounds of BOD leaving the secondary system with the effluent per day.
3. The total pounds of BOD removed per day by the secondary system.
4. The total dry pounds of secondary sludge produced per day by the secondary system.

Solution:

Known		Unknown
Flow, MGD	= 1.5 MGD	1. BOD Entering, lbs/day
Infl. BOD, mg/*L*	= 200 mg/*L*	2. BOD Leaving, lbs/day
Effl. BOD, mg/*L*	= 30 mg/*L*	3. BOD Removed, lbs/day
$\frac{\text{Y, lbs SI Sol Prod}}{\text{lb BOD Rem}}$	= $\frac{\text{0.50 lbs SI Sol}}{\text{lb BOD}}$	4. Sludge Prod., lbs/day

1. Determine the 5-day BOD entering the secondary system, lbs BOD/day.

Entering BOD, lbs BOD/day = Flow, MGD × BOD, mg/*L* × 8.34 lbs/gal
= 1.5 MGD × 200 mg/*L* × 8.34 lbs/gal
= 2502 lbs BOD/day

2. Determine the 5-day BOD leaving the secondary system, lbs BOD/day.

Leaving BOD, lbs BOD/day = Flow, MGD × BOD, mg/*L* × 8.34 lbs/gal
= 1.5 MGD × 30 mg/*L* × 8.34 lbs/gal
= 375 lbs BOD/day

3. Determine the 5-day BOD removed from the secondary system, lbs BOD/day.

Bod Removed, lbs BOD/day = Entering BOD, lbs BOD/day - Leaving BOD, lbs BOD/day
= 2502 lbs BOD/day - 375 lbs BOD/day
= 2127 lbs BOD/day

OR

$$\begin{aligned}\text{BOD Removed, lbs BOD/day} &= \text{Flow, MGD} \times (\text{In BOD, mg/}L - \text{Ef BOD, mg/}L) \times 8.34\ \text{lbs/gal}\\ &= 1.5\ \text{MGD} \times (200\ \text{mg/}L - 30\ \text{mg/}L) \times 8.34\ \text{lbs/gal}\\ &= 2127\ \text{lbs BOD/day}\end{aligned}$$

4. Determine the secondary sludge produced in terms of pounds of dry sludge solids per day.

$$\begin{aligned}\text{Sludge Produced, lbs dry solids/day} &= \text{BOD Removed, lbs BOD/day} \times \text{Y}, \frac{\text{lbs Sl Sol Prod/day}}{\text{lbs BOD Rem/day}}\\ &= 2127\ \text{lbs BOD/day} \times \frac{0.50\ \text{lbs Sl Sol/day}}{1\ \text{lb BOD/day}}\\ &= 1064\ \text{lbs dry sludge solids/day}\end{aligned}$$

3.02 Sludge Volumes

Examples 1 and 2 illustrated how to estimate the quantity or pounds of primary and secondary sludge solids, respectively. The total volume or gallons of primary and secondary sludges are equally as important for sizing sludge handling equipment. Sludge volumes in gallons are determined by the sludge solids content (% SS) and the pounds of solids in a sludge sample according to the following equation:

$$\boxed{\text{Sludge Volume, gal} = \frac{\text{Sludge Quantity, lbs dry solids}}{8.34\ \text{lbs/gal} \times \text{Sludge Solids, \%/100\%}}}$$

If the primary sludge from Example 2 is withdrawn from the primary clarifier at a sludge solids concentration (% Sl Sol) of 5 percent, the daily volume of sludge would be determined as follows:

Solution:

Known	Unknown
Primary Sludge Quantity lbs/day = 2502 lbs/day	Primary Sludge Volume, gal/day
Sludge Solids, % = 5%	

Determine the daily primary sludge volume in gallons per day.

$$\begin{aligned}\text{Primary Sludge Volume, gal/day} &= \frac{\text{Sludge Quantity, lbs dry solids/day}}{8.34\ \text{lbs/gal} \times \text{Sludge Solids, \%/100\%}}\\ &= \frac{2502\ \text{lbs/day}}{8.34\ \text{lbs/gal} \times 5\%/100\%}\\ &= \frac{2502}{8.34 \times 0.05}\\ &= 6{,}000\ \text{gal/day}\end{aligned}$$

Likewise, if the secondary sludge from Example 2 is withdrawn from the secondary clarifier at a sludge solids concentration (% Sl Sol) of 1.0 percent, the daily volume of sludge would be determined as follows:

Solution:

Known	Unknown
Secondary Sludge Quantity, lbs/day = 1064 lbs/day	Secondary Sludge Volume, gal/day
Sludge Solids, % = 1.0%	

Determine the daily secondary sludge volume in gallons per day.

$$\begin{aligned}\text{Secondary Sludge Volume, gal/day} &= \frac{\text{Sludge Quantity, lbs dry solids/day}}{8.34\ \text{lbs/gal} \times \text{Sludge Solids, \%/100\%}}\\ &= \frac{1064\ \text{lbs/day}}{8.34\ \text{lbs/gal} \times 1.0\%/100\%}\\ &= 12{,}758\ \text{gal/day}\end{aligned}$$

3.03 Sludge Handling Alternatives

Depending on the type and quantity of sludge produced, a variety of unit processes and overall sludge handling systems can be established to process the sludge. The schematic diagram presented in Table 3.1 illustrates these sludge processing alternatives. The remainder of this chapter will be divided into separate lessons on thickening, stabilization, conditioning, dewatering, volume reduction, and ultimate disposal of solids.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 247.

3.0A List the two types and general characteristics of sludges that are produced at a typical wastewater treatment facility.

3.0B List the variables that govern the quantity of primary sludge production.

3.0C Determine the daily quantity (lbs/day) of primary sludge produced for the following conditions: (1) influent flow of 2.0 MGD, (2) influent suspended solids of 200 mg/*L*, and (3) primary effluent suspended solids of 120 mg/*L*.

3.0D List the variables that influence the production of scondary sludges.

TABLE 3.1 SLUDGE PROCESSING ALTERNATIVES

	TYPE OF ALTERNATIVE					
	THICKENING	STABILIZATION	CONDITIONING	DEWATERING	VOLUME REDUCTION	DISPOSAL
OBJECTIVE	Remove water from the sludge mass	Convert odor-causing portion of sludge solids to nonodorous end products	Pretreatment of sludge to facilitate removal of water in subsequent treatment processes	Reduce sludge moisture and volume to allow economical disposal	Reduction of sludge mass prior to ultimate disposal	Ultimate disposal
SPECIFIC PROCESSES	1. Gravity	1. Digestion	1. Chemical	1. Filtration	1. Drying	1. Land
	2. Flotation	2. Thermal	2. Thermal	2. Centrifugation	2. Incineration	2. Ocean
	3. Centrifugation	3. Chemical	3. Elutriation	3. Drying Beds	3. Composting	3. Air

3.0E Estimate the daily quantity of secondary sludge produced for the following conditions: (1) influent flow of 2.0 MGD, (2) influent BOD to the secondary system of 180 mg/*L* and effluent from the secondary system of 30 mg/*L* and (3) growth rate coefficient, Y, of 0.50 pounds of solids per pound of BOD removed.

3.0F For the conditions given in problem 22.0C, estimate the daily volume (gal/day) of primary sludge if it is withdrawn from the primary clarifier at a sludge solids concentration of 4.0 percent.

3.1 THICKENING

3.10 Purpose of Sludge Thickening

Settled solids removed from the bottom of the primary clarifier (primary sludge) and settled biological solids removed from the bottom of secondary clarifiers (secondary sludge) contain large volumes of water. Typically, primary sludge contains approximately 95 to 97 percent water. For every pound of primary solids, there are 20 to 30 pounds of water and for every pound of secondary solids approximately 50 to 150 pounds of water are incorporated in the sludge mass. If some of the water is not removed from the sludge mass, the size of subsequent sludge handling equipment (digester, mechanical dewatering equipment, pumps) have to be larger to handle the greater volumes and this would obviously increase equipment costs.

Concentration or thickening is usually the first step in a sludge processing system following initial separation of solids by sedimentation from the wastewater being treated. Maximum sludge thickening should always be attempted in the sedimentation tank before using a separate sludge thickener. *THE PRIMARY FUNCTION OF SLUDGE THICKENING IS TO REDUCE THE SLUDGE VOLUME TO BE HANDLED IN SUBSEQUENT PROCESSES.* The advantages normally associated with sludge thickening include: (1) improved digester performance due to a smaller volume of sludge, (2) construction cost savings for new digestion facilities due to smaller sludge volumes treated, and (3) a reduction in digester heating requirements because less water has to be heated. Also reduced sludge volumes result in smaller facilities for storing, blending, dewatering and incinerating or disposing of the sludge. The following example illustrates the reduction in sludge volume when a sludge is thickened.

EXAMPLE 3.

Given: A primary sludge is withdrawn from a primary clarifier at a sludge solids concentration of 3.0 percent. The volume of sludge withdrawn is 2,000 gallons per day.

Find: 1. The amount of primary sludge solids withdrawn in pounds per day.

2. If the sludge is concentrated (thickened) to 5.0 percent sludge solids, find the new sludge volume.

Solution:

Known		**Unknown**
Sludge Solids, %	= 3.0%	1. Amount of Dry Sludge, lbs/day
Sludge Vol, gal/day	= 2000 gal/day	2. Thickened Sludge Volume, gal/day

1. Determine the amount of primary dry sludge withdrawn in pounds per day.

$$\text{Dry Sludge Solids, lbs/day} = \text{Sludge Vol, } \frac{\text{gal}}{\text{day}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}$$

$$= 2000 \frac{\text{gal}}{\text{day}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{3.0\%}{100\%}$$

$$= 500 \text{ lbs/day}$$

2. Calculate the new thickened sludge volume in gallons per day.

$$\text{Sludge Volume, gal/day} = \frac{\text{Dry Sludge Solids, lbs/day}}{8.34 \text{ lbs/gal} \times \text{Sl Sol, \%/100\%}}$$

$$= \frac{500 \text{ lbs/day}}{8.34 \text{ lbs/gal} \times 5.0\%/100\%}$$

$$= 1200 \text{ gal/day}$$

Although the pounds of sludge solids remained constant at 500 lbs/day, the total volume of sludge decreased from 2000 gal/day to 1200 gal/day when the sludge was thickened from 3 percent sludge solids to 5 percent sludge solids. Three unit processes commonly used to concentrate wastewater sludges include gravity, air flotation, and centrifuge thickeners. A discussion of each process is contained in this section.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 247.

3.10A What is the primay function of sludge thickening?

3.10B Determine the amount of dry sludge (lbs/day) if 12,000 gal/day of secondary sludge are produced with a solids concentration of 1.0%.

3.10C For the conditions given in problem 3.10B, determine the secondary sludge volume (gal/day) if the sludge is withdrawn from the secondary clarifier at a solids concentration of 1.5%.

3.11 Gravity Thickening

Gravity thickening of wastewater sludges uses gravity forces to separate solids from the sludges being treated. Those solids that are heavier than the water settle to the bottom of the thickener by virtue of gravity and are then compacted by the weight of the overlying solids. Gravity concentrators or thickeners are typically circular in design and resemble circular clarifiers. The main components of gravity thickeners, as shown in Figure 3.2 are: (1) the inlet and distribution assembly, (2) a sludge rake to move the sludge to a sludge hopper, (3) vertical steel members or "pickets" mounted on the sludge rake, (4) an effluent or overflow weir, and (5) scum removal equipment.

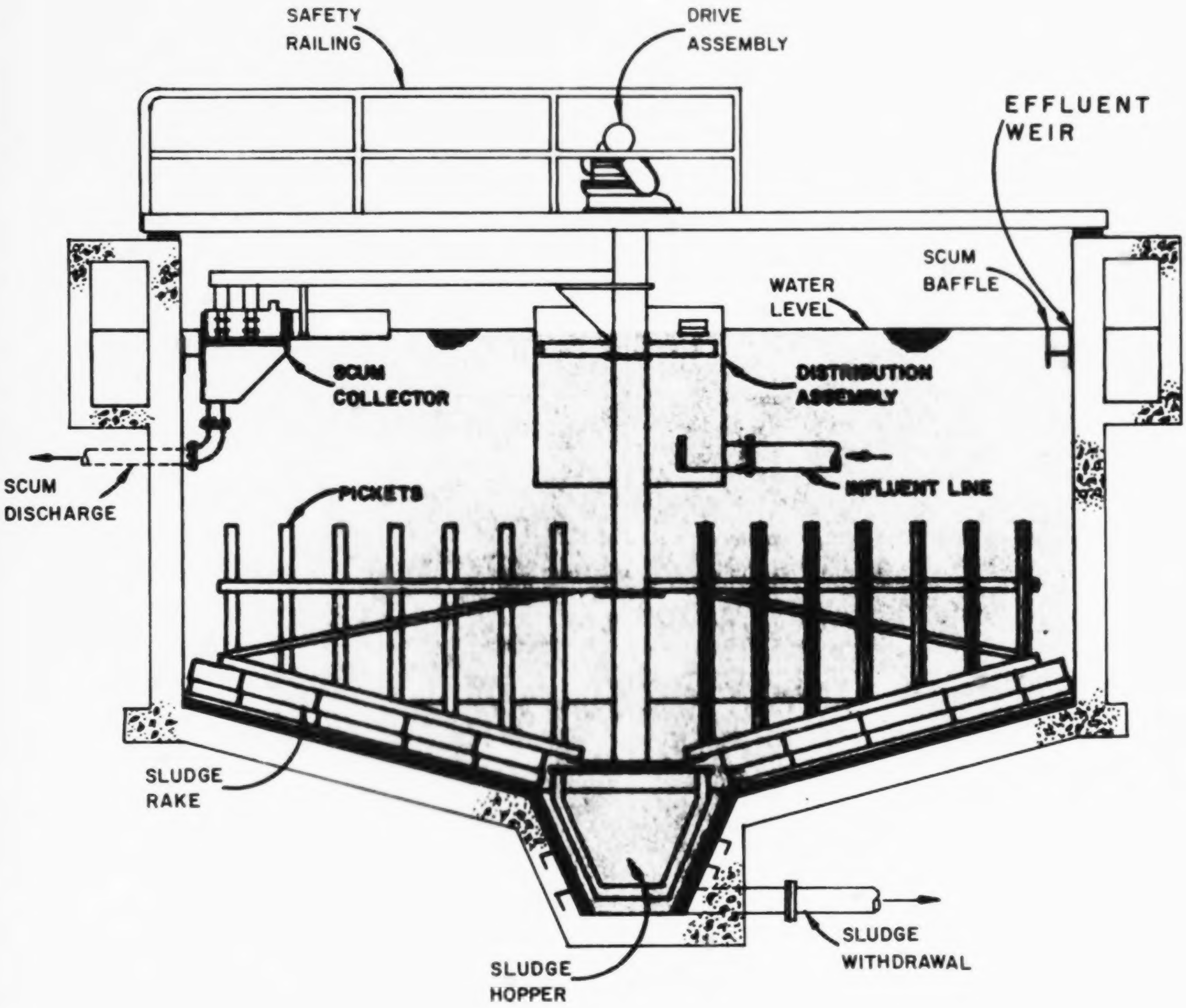
SAFETY RAILING
DRIVE ASSEMBLY
EFFLUENT WEIR
SCUM BAFFLE
WATER LEVEL
SCUM COLLECTOR
DISTRIBUTION ASSEMBLY
INFLUENT LINE
SCUM DISCHARGE
PICKETS
SLUDGE RAKE
SLUDGE WITHDRAWAL
SLUDGE HOPPER

Fig. 3.2 Gravity thickener

The inlet or distribution assembly usually consists of a circular steel skirt or *BAFFLE*[7] which originates above the water surface and extends downward approximately 2 to 3 feet (0.6 to 0.9 m) below the water surface. The sludge to be thickened enters the assembly, flows downward under the steel skirt and through the tank where the solids settle to the bottom. The inlet assembly provides for an even distribution of sludge throughout the tank and reduces the possibility of *SHORT-CIRCUITING*[8] to the effluent end of the thickener.

The sludge rake provides for movement of the settled (thickening) sludge. As the rake slowly rotates, the settled solids are moved to the center of the tank where they are deposited in a sludge hopper. The tank bottom is usually sloped towards the center to facilitate the movement of sludge to the collection point. Typically, sludge pumps include centrifugal recessed-impeller-type pumps or positive displacement progressive-cavity-type pumps.

The vertical steel member (pickets) that are usually mounted on the sludge rake assembly provide for gentle stirring or flocculation of the settled sludge as the rake rotates. This gentle stirring action serves two purposes. Trapped gases in the sludge are released to prevent *RISING*[9] of the solids. Also, stirring prevents the accumulation of a large volume of solids floating on the thickener surface that must be removed as scum and will create nuisance and odor problems.

The effluent or thickener overflow flows over a continuous weir located on the periphery (outside) of the thickener. The outlet works usually include an effluent baffle to retain floating debris and a scum scraper and collection system to remove these floatables.

3.110 Factors Affecting Gravity Thickeners

The successful operation of gravity thickeners is dependent on the following factors; (1) type of sludge, (2) age of the feed sludge, (3) sludge temperature, (4) sludge blanket depth, (5) solids and hydraulic detention times and (6) solids and hydraulic loadings. The first three factors deal with the characteristics of the influent sludge while the remaining three factors deal with operational controls.

Both the type and age of sludge to be thickened can have pronounced effects on the overall performance of gravity thickeners. Fresh primary sludge usually can be concentrated to the highest degree. If the primary sludge is septic or allowed to go *ANAEROBIC*,[10] hydrogen sulfide (H_2S), methane (CH_4), and carbon dioxide (CO_2) gases may be produced (*GASIFICATION*[11]). If gas is produced, it will attach to sludge particles and carry these solids to the surface. The net effect(s) of gas production due to anaerobic conditions will be reduced thickener efficiency and lower solids concentration.

Secondary sludges are not as well suited for gravity thickening as primary sludge. Secondary sludges contain large quantities of *BOUND WATER*[12] which makes the sludge less dense than primary sludge solids. Biological solids are composed of approximately 85 to 90 percent water by weight within the cell mass. The water contained within the cell wall is referred to as "bound water."

The fact that biological solids contain large volumes of cell water and are often smaller or finer in size than primary sludge solids makes them harder to separate by gravity concentration. The age of the secondary sludge also plays an important role in the efficiency of gravity thickening processes. In the activated sludge process, ammonia is converted to nitrite and nitrate according to the following equations:

$$\text{Ammonia } (NH_3) + \text{Oxygen} \rightarrow \text{Nitrite } (NO_2^-) + H_2O$$

$$\text{Nitrite } (NO_2^-) + \text{Oxygen} \rightarrow \text{Nitrate } (NO_3^-)$$

The conversion of ammonia to nitrite and then nitrate is termed "nitrification." This conversion will occur if sufficient oxygen and aeration time are alloted in the activated sludge process to permit the buildup of *NITRIFYING BACTERIA*.[13]

In the solids-liquid separation section (secondary sedimentation) of activated sludge wastewater treatment plants, the available oxygen in the settled sludge may be depleted to the point where no dissolved oxygen remains. If the sludge is held too long in the final clarifier or gravity thickener and the dissolved oxygen concentration decreases to zero, the nitrate can be converted to nitrogen gas. The conversion of nitrate to nitrogen gas is termed *DENITRIFICATION*.[14] Rising bubbles of nitrogen gas due to denitrification will carry settled solids to the surface of secondary clarifiers or gravity thickeners and will adversely affect process performance. Another problem occasionally encountered with activated sludge processes is "sludge bulking." If sufficient oxygen is not available in the aeration basin or nutrient imbalances are present, *FILAMENTOUS ORGANISMS*[15] may grow in the aeration basins. The predominance of these organisms will decrease the settleability of activated sludge and it will not settle as readily in the secondary clarifiers or compact to its highest degree in gravity thickeners. Greater compaction can be achieved by the addition of chemicals.

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[7] *Baffle. A flat board or plate, deflector, guide or similar device constructed or placed in flowing water, wastewater, or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids.*

[8] *Short-Circuiting. A condition that occurs in tanks or ponds when some of the water or wastewater travels faster than the rest of the flowing water.*

[9] *Rising Sludge. Rising sludge occurs when sludge settles to the bottom of the thickener, is compacted, and then starts to rise to the surface, usually as a result of denitrification.*

[10] *Anaerobic (AN-air-O-bick). A condition in which "free" or dissolved oxygen is NOT* present in the aquatic environment.

[11] *Gasification (GAS-i-fi-KAY-shun). The conversion of soluble and suspended organic materials into gas during anaerobic decomposition. In anaerobic sludge digesters, this gas is collected for fuel or disposed of using the waste gas burner.*

[12] *Bound Water. Water contained within the cell mass of sludges or strongly held on the surface of colloidal particles.*

[13] *Nitrifying Bacteria. Bacteria that change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate).*

[14] *Denitrification. A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers or gravity thickeners.*

[15] *Filamentous Organisms (FILL-a-MEN-tuss). Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomyces.*

Another sludge characteristic which affects the degree of thickening is the temperature of the sludge. As the temperature of the sludge (primary or secondary) increases, the rate of biological activity is increased and the sludge tends to gasify and rise at a faster rate. During summertime (warm weather) operation, the settled sludge has to be removed at a faster rate from the thickener than during wintertime operation. When the sludge temperature is lower during the winter, biological activity and gas production proceed at a slower rate.

Solids and hydraulic retention times and loadings are discussed in the next section which reviews operating guidelines.

3.111 Operating Guidelines

The size of gravity thickeners is determined and designed by engineers. *THE OPERATOR CONTROLS THE SOLIDS RETENTION TIME WITHIN THE THICKENER AND REACHES PEAK PERFORMANCE BY CONTROLLING THE SPEED OF THE SLUDGE COLLECTION MECHANISM (IF POSSIBLE), ADJUSTING THE SLUDGE WITHDRAWAL RATE AND CONTROLLING THE SLUDGE BLANKET DEPTH.* Successful operation of gravity concentrators requires that the operator be able to calculate applied loading rates and sludge detention time, and be aware of the available controls.

3.1110 Hydraulic and Solids Loadings. The hydraulic surface loading or overflow rate is defined as the total number of gallons applied per square foot of thickener water surface area per day (gpd/sq ft). To calculate hydraulic surface loading, first determine the total water surface area in square feet. Then divide the number of gallons applied per day by the surface area (sq ft). The gallons applied usually include more than just the sludge pumped, because it is better to keep a good high flow of fresh liquid entering the thickener to prevent septic conditions and odors from developing. To accomplish this higher flow, secondary effluent is usually blended with the sludge feed to the thickener. Typical hydraulic loading rates are from 400 to 800 gpd/sq ft (16 to 32 cu m per day/sq m). For a very thin mixture or for waste activated sludge (WAS) only, hydraulic loading rates of 100 to 200 gpd/sq ft (4 to 8 cu m per day/sq m) would be appropriate.

EXAMPLE 4

Given: A 20-foot diameter gravity thickener is used to thicken 20 GPM of primary sludge. 80 GPM of secondary effluent is blended with the raw sludge to prevent septic conditions and odors.

Find: The hydraulic surface loading applied to the gravity thickener.

Solution:

Known		Unknown
Thickener Diameter, ft	= 20 feet	Hydraulic Surface Loading, gpd/sq ft
Sludge Flow, GPM	= 20 GPM	
Blend Flow, GPM	= 80 GPM	
Total Flow, GPM	= 100 GPM	

Determine the flow in gallons per day and the water surface area in square feet. Calculate the hydraulic surface loading in gallons per day (gpd) per square foot.

$$\text{Hydraulic Surface Loading, gpd/sq ft} = \frac{\text{Total Flow, gal/min} \times 60\ \text{min/hr} \times 24\ \text{hr/day}}{\frac{\pi}{4} \times (\text{Diameter, ft})^2}$$

$$= \frac{100\ \text{gal/min} \times 60\ \text{min/hr} \times 24\ \text{hr/day}}{\frac{\pi}{4} \times (20\ \text{ft})^2}$$

$$= \frac{144{,}000\ \text{gpd}}{314\ \text{sq ft}}$$

$$= 460\ \text{gpd/sq ft}$$

The solids loading is defined as the total number of pounds of solids applied per square foot of thickener surface area per day. To calculate the solids loading, first find the total surface area (sq ft) of the thickener. Next, using the flow rate and solids concentration, calculate the total pounds of solids applied per day. Finally, divide the total solids (lbs/day) by the total surface area (sq ft) to find the solids loading. The proper operating solids loading will vary with the type of sludge. Typical values are discussed in Section 22.113, "Typical Performance."

EXAMPLE 5

Given: A 45-foot diameter gravity thickener is used to thicken 100 GPM of primary sludge. The primary sludge is applied to the thickener at an initial sludge solids concentration of 3.5 percent.

Find: The solids loading (S.L.) applied to the gravity thickener in lbs/day per sq ft.

Solution:

Known		Unknown
Thickener Diameter, ft	= 45 feet	Solids Loading, lbs/day/sq ft
Sludge Flow, GPM	= 100 GPM	
Sludge Solids, %	= 3.5%	

Determine the solids applied to the thickener in pounds per day.

$$\text{Solids Applied, lbs/day} = \text{Flow, gpd} \times 8.34\ \text{lbs/gal} \times \frac{\text{Solids, \%}}{100\%}$$

$$= 100\ \text{gal/min} \times 1440\ \text{min/day} \times 8.34\ \text{lbs/gal} \times \frac{3.5\%}{100\%}$$

$$= 42{,}034\ \text{lbs/day}$$

Calculate the solids loading.

$$\text{Solids Loading, lbs/day/sq ft} = \frac{\text{Solids Applied, lbs/day}}{\text{Surface Area, sq ft}}$$

$$= \frac{42{,}034\ \text{lbs/day}}{\frac{\pi}{4}(45\ \text{ft})^2}$$

$$= 26\ \text{lbs/day/sq ft}$$

3.1111 Sludge Detention Time. The sludge detention time is defined as the length of time the solids remain in the gravity thickener. This time is based on the amount of solids applied, the depth and concentration of the sludge blanket, and the quantity of solids removed from the bottom of the thickener. The operator has the ability to *CONTROL THE SOLIDS DETENTION TIME AND THE DEGREE OF THICKENING TO SOME EXTENT BY CONTROLLING THE DEPTH OF THE SLUDGE BLANKET.* If the blanket is maintained at too high a level and the solids detention time is excessive, gasification may develop with subsequent rising sludge and deterioration of effluent quality. The actual response of a particular sludge to gravity thickening depends on the treatment plant. Trial and error procedures usually determine the best operation. To aid the operator in controlling the detention time of the solids in the thickener, the sludge-volume ratio (SVR) term is used. SVR is defined as the volume of the sludge blanket divided by the daily volume of sludge pumped from the thickener. This term is a relative measure of the average detention time of solids in the thickener and is calculated in days. Typical SVR values are between 0.5 and 2.0 days. The higher SVRs are desirable for a maximum sludge concentration; however, to guard against gasification, the lower SVR values are maintained during warm weather.

3.112 Normal Operating Procedures

Typically, the flow through the thickener is continuous and should be controlled to be as constant as possible. Monitoring of the influent, effluent and concentrated sludge streams should be done at least once per shift and should include collection of samples for later laboratory analysis.

Under normal operating conditions, water at the surface should be relatively *CLEAR* and free from solids and gas bubbles. The sludge blanket depth is usually kept around 5 to 8 feet (1.5 to 2.4 m). The speed of the sludge collectors should be fast enough to allow the settled solids to move towards the sludge collection pump. The bottom sludge collectors should not be operated at speeds that will disrupt the settled solids and cause them to float to the surface. Sludge withdrawal rates should be sufficient to maintain a constant blanket level.

Normal start-up and shutdown procedures for placing a thickener in or out of service are outlined below.

Start-Up

— Turn on the sludge collectors and scum collection equipment.

— Activate chemical conditioning systems, if used.

— Open all appropriate inlet valves.

— Turn on and adjust, if possible, the influent sludge pump.

— Check the sludge blanket depth.

— Open all appropriate sludge withdrawal valves.

— Set the sludge pump in the automatic "ON" position.

— Routinely check the blanket depth and thickened sludge concentration and adjust the withdrawal rate as required.

The thickener should be operated continuously. However, if the thickener is not operated as a continuous process and daily or frequent shutdowns are required, the following procedures should be followed:

Shutdown

— Turn off the influent sludge pump and close appropriate inlet valves.

— Turn off the chemical addition equipment, if chemical conditioning is used.

— Allow the scum collection and sludge collection removal systems to operate until the water surface is free of floating material and settled sludge has been removed from the thickener bottom.

— Turn off the scum collection, sludge collection and sludge withdrawal equipment.

— Hose down and clean up the area as required.

3.113 Typical Performance

Typical loadings and thickener output concentrations for various sludge types are summarized in Table 3.2. Note that the data presented in Table 3.2 is generalized and the actual response of a particular sludge at a particular plant may vary significantly.

TABLE 3.2 OPERATIONAL AND PERFORMANCE GUIDELINES FOR GRAVITY THICKENERS

Sludge Type	Solids Loading, lbs/day/sq ft*	Thickened Sludge, %
Separate		
Primary	20-30	8-10
Activated Sludge	5-8	2-4
Trickling Filter	8-10	7-9
Combined		
Primary & Act. Sl.	6-12	4-9
Primary & Trickling Filter	10-20	7-9

* lbs/day/sq ft × 4.883 = kg/day/sq m

In order to rate the performance of gravity thickeners, the operator must be familiar with the calculations required to determine process efficiency.

The efficiency of any process in removing a particular constituent is determined by the following equation:

$$\text{Efficiency, \%} = \frac{(\text{Influent-Effluent})}{\text{Influent}} \times 100\%$$

In the case of gravity thickeners, suspended or sludge solids removal is a key performance factor. One of the goals of the operator should be to remove as much of the influent solids as possible. Usually the supernatant or overflow from the thickener is returned to the plant headworks. If the solids concentration in this stream is high, then you are recirculating solids and can end up "chasing your tail" (having to treat more and more solids). The following example shows how to calculate sludge solids removal efficiency for a gravity thickener.

EXAMPLE 6

Given: A gravity thickener receives 20 GPM of primary sludge at a concentration of 3.0 percent sludge solids (30,000 mg/*L*). The effluent from the thickener contains 0.15 percent (1500 mg/*L*) of sludge solids.

Find: The efficiency in removing sludge solids.

Solution:

Known		Unknown
Gravity Thickener		Thickener Efficiency, %
Flow, GPM (Primary Sludge)	= 20 GPM	
Infl SS, %	= 3.0%	
Infl SS, mg/*L*	= 30,000 mg/*L*	
Effl SS, %	= 0.15%	
Effl SS, mg/*L*	= 1,500 mg/*L*	

Determine the thickener efficiency in removing sludge solids.

$$\begin{aligned}\text{Efficiency, \%} &= \frac{(\text{Infl SS, mg}/L - \text{Effl SS, mg}/L) \times 100\%}{\text{Infl SS, mg}/L}\\ &= \frac{(30{,}000\ \text{mg}/L - 1{,}500\ \text{mg}/L) \times 100\%}{30{,}000\ \text{mg}/L}\\ &= 95\%\end{aligned}$$

Concentrating the sludge and thereby reducing the volume to be pumped to subsequent processes is the main goal of the operator. A concentration factor should be used to determine the effectiveness of the thickener in concentrating the sludge. The concentration factor (cf) is determined by the following equation:

$$\text{Concentration factor (cf)} = \frac{\text{Thickened Sludge Conc., \%}}{\text{Influent Sludge, Conc. \%}}$$

The following example illustrates the use of the above equation.

EXAMPLE 7

Given: A primary sludge with a concentration of 3.0 percent sludge solids is thickened to a concentration of 7.0 percent sludge solids.

Find: The concentration factor (cf).

Solution:

Known		Unknown
Primary Sludge Conc., %	= 3.0%	Concentration Factor
Thickened Sludge Conc., %	= 7.0%	

$$\begin{aligned}\text{Concentration Factor} &= \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}}\\ &= \frac{7.0\%\ \text{Sludge Solids}}{3.0\%\ \text{Sludge Solids}}\\ &= 2.33\end{aligned}$$

The concentration factor determined above means that the influent sludge was thickened to a concentration 2.33 times its initial concentration. For primary sludges, the operator should achieve concentration factors of 2.0 or higher. Concentration factors for secondary sludges should be 3.0 or greater.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 248.

3.11A List the main components of gravity thickeners.

3.11B Discuss the function of the inlet baffle, sludge rakes, and vertical pickets.

3.11C Discuss how the age of sludge may affect gravity concentration of primary and waste activated sludges.

3.11D How does sludge temperature affect the efficiency of gravity thickeners and what measure should be taken during summertime operation to reduce gas production and rising sludge.

3.11E Determine the hydraulic surface (gpd/sq ft) and solids loading (lbs/day/sq ft) to a 30-ft diameter gravity thickener if 60 GPM of primary sludge at an initial suspended solids concentration of 3.0 percent sludge are applied.

3.11F A gravity thickener is used to concentrate 40 GPM of waste activated sludge at a concentration of 0.9% (9,000 mg/*L*). The underflow sludge is withdrawn at 3 percent and the effluent suspended solids concentration is 1,800 mg/*L*. Determine the suspended solids removal efficiency (%) and the concentration factor.

3.114 Troubleshooting

VISUAL INSPECTION OF MOST WASTEWATER TREATMENT UNIT PROCESSES COUPLED WITH AN UNDERSTANDING OF THE EXPECTED RESULTS (COMPARE DESIGN VALUES WITH OPERATING CRITERIA) FROM GOOD PERFORMANCE ARE THE KEYS TO SUCCESSFUL OPERATION. More often than not, the operator is made aware of equipment malfunctions and/or decreases in process efficiency by observing such items as liquid surfaces and effluent quality and also being aware of uncharacteristic odors. Enough emphasis cannot be placed on the *OPERATOR'S AWARENESS* and ability to *RECOGNIZE SIGNS OF TROUBLE.* In most instances, the experienced operator has the ability to ward off major operational problems and to maintain efficient operation by careful inspection and operational adjustments.

The specific areas of concern regarding gravity thickeners are: (1) surface and overflow quality, and (2) sludge blanket depth and thickened sludge concentrations.

3.1140 Liquid Surface. As previously discussed, the overflow or effluent should be relatively clear (less than 500 mg/*L* suspended solids) and the liquid surface should be free of gas bubbles. If the operator notices an excessively high carryover of suspended solids, attention should immediately focus on the hydraulic loading and signs of gasification. If gas bubbles are evident at the tank surface, the problem may be caused by an excessive sludge detention time and subsequent gasification. The action(s) to be taken should include a determination of sludge blanket depth and a visual estimate of the thickened solids concentration. If the problem is related to an excessive sludge retention time, the thickened sludge concentration will be thicker than normal and the depth of the sludge blanket will be higher than usual.

To correct the problem, the operator should increase the rate of sludge withdrawal from the bottom of the thickener or lower the feed rate, if possible. Once a change of this nature is made, the operator should periodically check the condition of the effluent and the thickened (underflow) solids so as not to completely remove the sludge blanket and drastically reduce the thickened sludge concentration.

If the sludge blanket depth and solids concentrations are not high enough to be considered for causes of gasification, the operator should investigate the speed of the sludge collectors and the influent characteristics. Sludge collection equipment may be equipped with a variable speed mechanism. If the scrapers are operating at too low of a speed, gasification may develop because pickets are not stirring the sludge and releasing the gas. Another common cause of gasing in gravity thickeners is the age of the influent sludge. If the sludge is held too long in the primary and/or secondary clarifiers, it may be well on its way to releasing gas before it enters the thickener. If gasing in the thickener cannot be attributed to operation of the thickener, the operator should observe the influent sludge and adjust the rate of sludge to the thickener. Secondary effluent can be recirculated to the thickener to freshen the influent sludge.

If poor effluent quality cannot be attributed to gasification, the problem may be the result of malfunctions in chemical conditioning equipment or increased hydraulic loadings. Chemical conditioning will be covered in Section 22.31, but the operator should be aware that chemical underdosing or overdosing can lead to equipment inefficiencies and should inspect the chemical addition equipment. Hydraulic loadings in excess of design values also may lead to solids carryover and decreased efficiency. The operator should check the rate of sludge pumping to the thickener, determine the hydraulic loading according to the calculations presented in Example 4 and adjust the thickener feed rate for successful operation. Coagulating chemicals may be used if the effluent quality needs improvement.

3.1141 Thickened Sludge Concentration. Even if the thickener appears to be operating effectively as evidenced by the lack of gas on the surface and solids carryover with the effluent, the operator should periodically check the thickened sludge concentration and the blanket depth. The main objective of sludge thickening is to produce as concentrated a sludge as possible to effect volume reductions and cost savings in subsequent processes. If the thickened sludge concentration is not as thick as desired, the operator should check the blanket depth before making any adjustment to the withdrawal rate. On occasion, sludge in primary sedimentation tanks and gravity thickeners can become very thick and resistant to pumping. If this happens, a "hole" (*CONING*[16]) can develop in the blanket and liquid from above the blanket can be pulled through the pump. Lowering the rate of sludge withdrawal would increase the amount of solids at the bottom of the thickener and eventually result in *SEPTICITY*[17] and rising sludge. A hole (cone) in the sludge blanket (indicated by a low thickened sludge concentration and a high blanket level) can best be corrected by: (1) lowering the flow to the affected thickener, (2) increasing the speed of the collectors to keep the sludge at the point of withdrawal, and (3) increasing the rate of thickened sludge pumping. If both the blanket and the thickened sludge solids concentrations are low, the operator should lower the rate of sludge withdrawal in accordance with the calculations outlined below.

With time and experience, the opeator should be able to roughly estimate the concentration of the influent and thickened sludges. This ability to "eyeball" concentrations coupled with previous performance data should enable the operator to control withdrawal rates.

EXAMPLE 8

Given: A 40-foot diameter by 10-foot SWD (Side Water Depth) gravity thickener is used to concentrate 100 GPM of primary sludge. The primary sludge enters the thickener at approximately 3.5 percent based on the previous week's data. The sludge is withdrawn from the bottom of the thickener at 40 GPM at a concentration of 7.0 percent. The thickener effluent has a suspended solids concentration of 700 mg/*L* and the sludge blanket is 3 feet thick.

Find:
1. The sludge detention time in hours.
2. If the present influent and effluent conditions are maintained, will the sludge blanket increase or decrease in depth?
3. What changes should be made if a higher concentration of underflow (thickened sludge) solids is desired?
4. What changes would stop gasification? How would these changes affect thickened sludge concentrations?

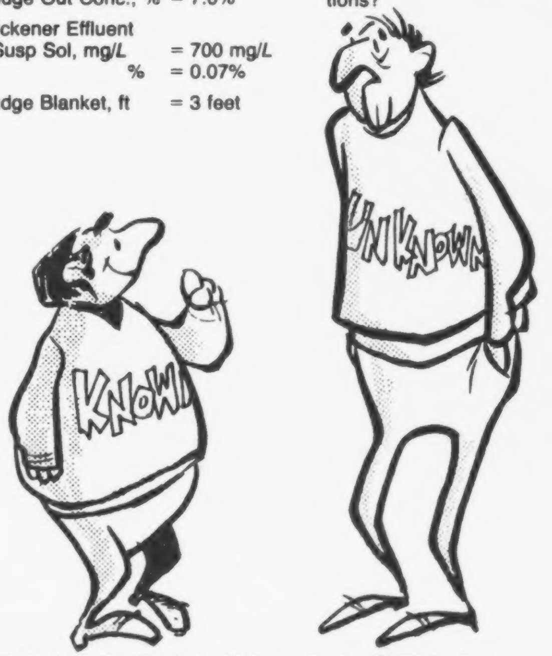
Solution:

Known

Gravity Thickener
Diameter, ft = 40 feet
Side Water Depth, ft = 10 feet
Flow In, GPM (Primary sludge) = 100 GPM
Sludge Out, GPM = 40 GPM
Primary Sludge Conc., % = 3.5%
Sludge Out Conc., % = 7.0%
Thickener Effluent Susp Sol, mg/*L* = 700 mg/*L*
% = 0.07%
Sludge Blanket, ft = 3 feet

Unknown

1. Sludge - Volume Ratio, days
2. Will sludge blanket increase or decrease?
3. What changes would increase underflow sludge concentrations?
4. What changes would stop gasification? How would these changes affect thickened sludge concentrations?



1. Calculate the Sludge - Volume Ratio (SVR) in days.

   a. Determine the sludge blanket volume in gallons.

$$\text{Sludge Blanket Volume, gal} = \frac{\pi}{4} \times (\text{Diameter, ft})^2 \times \text{Blanket, ft} \times \frac{7.48\text{ gal}}{\text{cu ft}}$$

$$= \frac{\pi}{4} \times (40\text{ ft})^2 \times 3\text{ ft} \times \frac{7.48\text{ gal}}{\text{cu ft}}$$

$$= 28{,}200\text{ gallons}$$

   b. Determine the sludge pumped in gallons per day.

$$\text{Sludge Pumped, gal/day} = \text{Sludge Out, GPM} \times 1440\,\frac{\text{min}}{\text{day}}$$

$$= 40\,\frac{\text{gal}}{\text{min}} \times 1440\,\frac{\text{min}}{\text{day}}$$

$$= 57{,}600\text{ gal/day}$$

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[16] *Coning (CONE-ing). Development of a cone-shaped flow of liquid, like a whirlpool, through sludge. This can occur in a sludge hopper during sludge withdrawal when the sludge becomes too thick. Part of the sludge remains in place while liquid rather than sludge flows out of the hopper. Also called "coring."*

[17] *Septicity (sep-TIS-it-tee). Septicity is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.*

c. Calculate the Sludge - Volume Ratio (SVR) in days.

$$\text{SVR, days} = \frac{\text{Sludge Blanket Volume, gal}}{\text{Sludge Pumped, gal/day}}$$

$$= \frac{28{,}200\text{ gal}}{57{,}600\text{ gal/day}}$$

$$= 0.5\text{ days}$$

2. Will the sludge blanket increase or decrease? If the quantity of solids entering the thickener is greater than the quantity leaving the thickener, then the blanket depth will increase. If the quantity of solids entering the thickener is less than the quantity leaving the thickener, the blanket thickness will decrease. The solution to this problem is based on mass balance calculations, as shown below:

   a. Determine the pounds of sludge solids entering the thickener daily.

$$\begin{array}{l}\text{Sludge Solids}\\\text{Entering,}\\\text{lbs/day}\end{array} = \text{Flow In, GPM} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl In, \%}}{100\%}$$

$$= 100\,\frac{\text{gal}}{\text{min}} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{3.5\%}{100\%}$$

$$= 42{,}034\text{ lbs/day}$$

   b. Determine the pounds of sludge solids withdrawn in the thickener underflow daily.

$$\begin{array}{l}\text{Sludge Solids}\\\text{Withdrawn,}\\\text{lbs/day}\end{array} = \text{Sludge Out, GPM} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Out \%}}{100\%}$$

$$= 40\,\frac{\text{gal}}{\text{min}} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{7.0\%}{100\%}$$

$$= 33{,}627\text{ lbs/day}$$

   c. Determine the pounds of solids lost in the thickener effluent daily.

$$\begin{array}{l}\text{Solids Lost in}\\\text{Effl, lbs/day}\end{array} = \text{Flow, GPM} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Effl \%}}{100\%}$$

$$= (100\text{ GPM-}40\text{ GPM}) \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.07\%}{100\%}$$

$$= 60\,\frac{\text{gal}}{\text{min}} \times 1440\,\frac{\text{min}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.07\%}{100\%}$$

$$= 504\text{ lbs/day}$$

   d. Determine total pounds of solids removed daily.

$$\begin{array}{l}\text{Solids Out,}\\\text{lbs/day}\end{array} = \begin{array}{l}\text{Sludge Solids}\\\text{Withdrawn, lbs/day}\end{array} + \begin{array}{l}\text{Solids Lost in}\\\text{Effl, lbs/day}\end{array}$$

$$= 33{,}627\text{ lbs/day} + 504\text{ lbs/day}$$

$$= 34{,}131\text{ lbs/day}$$

   e. Compare the sludge solids in with the solids out.

$$\begin{array}{l}\text{Sludge Solids}\\\text{Entering,}\\\text{lbs/day}\end{array} = 42{,}034\text{ lbs/day}$$

$$\begin{array}{l}\text{Solids Out,}\\\text{lbs/day}\end{array} = 34{,}131\text{ lbs/day}$$

   Therefore, since the solids entering (42,034 lbs/day) are greater than the solids out (34,131 lbs/day), the sludge blanket will increase in depth.

3. What changes would increase the thickened sludge concentration? Higher thickened sludge solids concentration will normally result if the depth of the sludge blanket is increased. To increase the blanket depth, the flow rate of the thickened sludge should be decreased somewhat. The thickened sludge is at a rate of 40 GPM *AND THE RATE SHOULD NOT BE CHANGED AT INCREMENTS OF GREATER THAN 20 PERCENT WHEN STEADY STATE CONDITIONS EXIST. DRASTIC CHANGES SHOULD BE AVOIDED* and a close watch should be kept over the depth of the blanket after such changes are made. To increase the sludge blanket depth and the thickened sludge concentration, the sludge withdrawal rate should be decreased to approximately 40 GPM - (40 GPM × 20%/100%) = 40 GPM − 8.0 GPM = 32 GPM.

   Another approach to regulating the sludge blanket depth is to sound (measure) the depth of the sludge blanket. In general, if the depth is greater than 7 feet (2.1 m), increase the underflow withdrawal rate and if the depth is less than 5 feet (1.5 m), decrease the withdrawal rate.

4. What changes would stop gasification? How would these changes affect thickened sludge concentrations?

   If gasification develops as a result of excessive sludge retention times, the rate of the sludge withdrawal should be increased so as to lower the sludge blanket depth with subsequent lowering of the sludge retention time. The net effect on thickener performance will be a decrease in thickened sludge concentration and a possible improvement in effluent quality. Another alternative may be to recirculate secondary effluent to freshen the sludge.

EXAMPLE 9

Given: The thickener from Example 8 has just been restarted following routine maintenance shutdown. The influent concentration is "eyeballed" at approximately 3.0 percent sludge solids. The influent flow is 150 gpm and the sludge withdrawal pump is set at 15 gpm. After a few hours of continuous operation, the sludge blanket depth is measured and found to be 2 feet thick. The underflow concentration is estimated to be approximately 6 percent.

Find: Should the operator increase, decrease, or maintain the current rate of withdrawal?

Solution:

Known		**Unknown**
Known information from Example 8		Should rate of sludge withdrawal be increased, decreased, or not changed?
Infl Sl Conc, %	= 3.0% Sl Sol	
Infl Flow, GPM	= 150 GPM	
Sludge Withdrawal Pump, GPM	= 15 GPM	
Sludge Blanket Depth, ft	= 2 ft	
Thickened Sl Conc, %	= 6.0% Sl Sol	

1. Calculate the sludge solids entering in pounds per minute.

$$\begin{array}{l}\text{Solids Entering,}\\\text{lbs/min}\end{array} = \text{Infl Flow, GPM} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol In, \%}}{100\%}$$

$$= 150\text{ gal/min} \times 8.34\text{ lbs/gal} \times 3.0\%/100\%$$

$$= 37.5\text{ lbs/min}$$

2. Calculate the sludge solids leaving the thickener in pounds per minute.

$$\begin{array}{l}\text{Solids Withdrawn,}\\\text{lbs/min}\end{array} = \text{Underflow, GPM} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Unfl Sl, \%}}{100\%}$$

$$= 15\,\frac{\text{gal}}{\text{min}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{6.0\%}{100\%}$$

$$= 7.5\text{ lbs/min}$$

The number of pounds exiting with the effluent can be neglected if the effluent is clear (less than 500 mg/*L* suspended solids) and little solids carryover is observed.

Based on the visual estimations of sludge concentration and the above calculations, sludge is being stored at the rate of 30.0 lbs/min (lbs enter-lbs exit). The sludge blanket depth is 2 feet but let us assume typical operation for this thickener indicates that a blanket depth of 5 feet can be maintained. The operator should therefore determine the time required to fill the thickener with 3 additional feet of sludge at the present conditions. The calculations are shown below.

$$\begin{aligned}\text{Storage Time, min} &= \frac{\text{Storage Volume, cu ft} \times \dfrac{62.4\text{ lbs}}{\text{cu ft}} \times \dfrac{\text{Unfl Sl \%}}{100\%}}{\text{Sludge Storage Rate, lbs/min}}\\ &= \frac{\dfrac{\pi}{4} \times (40\text{ ft})^2 \times 3\text{ ft} \times \dfrac{62.4\text{ lbs}}{\text{cu ft}} \times \dfrac{6.0\%}{100\%}}{30\text{ lbs/min}}\\ &= 470\text{ min}\end{aligned}$$

$$\begin{aligned}\text{Storage Time, hrs} &= \frac{470\text{ min}}{60\text{ min/hr}}\\ &= 7.8\text{ hours}\end{aligned}$$

If the unit is left as is, the blanket will reach a depth of 5 feet in approximately 8 hours. However, at the end of the 8 hours, the operator will again have to adjust the withdrawal rate to avoid even greater buildup of sludge blanket. Drastic changes in withdrawal rates are not desirable and can be avoided by making a slight adjustment at the start of the 8-hour period. This adjustment should be made based on the ratio of volume stored to total storage volume as shown below.

$$\begin{aligned}\text{Sludge Storage Rate, lbs/min} &= \frac{(\text{Stored Sludge Height, ft})}{\text{Total Storage Height, ft}} \times \text{Solids Entering, lbs/min}\\ &= \frac{2\text{ ft}}{5\text{ ft}} \times 37.5\text{ lbs/min}\\ &= 15\text{ lbs/min}\end{aligned}$$

We, therefore, want to store solids at a rate of 15 lbs/min instead of the current 30 lbs/min. To obtain this storage rate, the desired sludge withdrawal rate must be determined in pounds per minute.

$$\begin{aligned}\text{Sludge Withdrawal Rate, lbs/min} &= \text{Solids Entering, lbs/min} - \text{Sludge storage Rate, lbs/min}\\ &= 37.5\text{ lbs/min} - 15\text{ lbs/min}\\ &= 22.5\text{ lbs/min}\end{aligned}$$

The sludge withdrawal pumping rate must be increased in order to remove underflow solids at a rate of 22.5 pounds per minute.

$$\begin{aligned}\text{Sludge Withdrawal Pumping Rate, GPM} &= \frac{\text{Sludge Withdrawal, lbs/min}}{8.34\text{ lbs/gal} \times \text{Unfl Sl, \%/100\%}}\\ &= \frac{22.5\text{ lbs/min}}{8.34\text{ lbs/gal} \times \dfrac{6.0\%}{100\%}}\\ &= 45\text{ GPM}\end{aligned}$$

The sludge withdrawal pumping rate should therefore be increased from 15 GPM to 45 GPM at this time. This change represents a 200 percent increase in withdrawal rate which is substantially greater than the 20 percent change outlined in Example 8. In Example 8, the thickener was operating under steady state (lbs in = lbs out) conditions and under such conditions the withdrawal rate should not be changed by increments greater than 20 percent. For this example, the thickener is not at steady state and the formulas outlined above should govern the withdrawal rate changes. Approximately 4 hours after the above change is made the operator should re-check the blanket depth, sludge concentrations and effluent quality, rerun the above calculation and change the withdrawal rate, if required.

Table 3.3 summarizes the operational problems that may develop and lists the corrective measures that might correct such problems.

TABLE 3.3 TROUBLESHOOTING GRAVITY THICKENERS

Operational Problem	Possible Causes	Check or Monitor	Possible Solutions
1. Liquid level clear but sludge rising and solids carry-over	1. a. Gasification b. Septic feed c. Blanket disturbances d. Chemical inefficiencies e. Excessive loadings	1. a. Sludge blanket and sludge detention b. Characteristics of feed c. Sludge collector speed d. Chemical equipment e. Hydraulic flow rate	1. a. Increase sludge withdrawal rate b. Increase sludge pumping from clarifier c. Lower collector speed* d. Increase chemical feed rate e. Lower flow if possible
2. Thin (dilute) underflow sludge and clear effluent	2. a. Low blanket b. Sludge withdrawal rate too high	2. a. Blanket level	2.a. Decrease sludge withdrawal rate
3. Thin (dilute) underflow sludge, liquid level clear but sludge rising with solids carryover	3. a. Collector speed too low or inoperative b. Hole or cone in sludge blanket	3. a. Collector mechanism and speed b. Blanket level	3. a. Turn on and/or increase collector speed b. Increase collector speed and increase withdrawal rate
4. Thin (dilute) underflow sludge, liquid surface laden with solids and solids carryover	4. a. Hydraulic loading high b. Chemical system inoperative	4. a. Loadings. Influent sludge b. Chemical equipment	4. a. Lower influent sludge flow b. Increase chemical rate

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* If solids carryover is caused by gasification, increase collector speed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 248 and 249.

3.11G Why should the operator make routine visual checks on gravity thickeners as well as any other equipment?

3.11H What is the meaning of the term "hole" in the blanket and how can it be corrected?

3.11I A gravity thickener has been operating successfully. On a routine check the operator notices that solids are rising to the surface. List the possible causes and outline the procedures the operator should follow to correct the problem(s).

3.12 Dissolved Air Flotation Thickeners

The objective of flotation thickening is to separate solids from the liquid phase in an upward direction by attaching air bubbles to particles of suspended solids. Four general methods of flotation are commonly employed. These include:

1. Dispersed air flotation where bubbles are generated by mixers or diffused aerators.
2. Biological flotation where gases formed by biological activity are used to float solids.
3. Dissolved air (vacuum) flotation where water is aerated at atmospheric pressure and released under a vacuum.
4. Dissolved air (pressure) flotation where air is put into solution under pressure and released at atmospheric pressure.

Flotation by dissolved air (pressure) is the most commonly used procedure for wastewater sludges and will be the topic of discussion in this section. Flotation units may be either rectangular or circular in design. The dissolved air system employs either a compressed air supply or an *ASPIRATOR-TYPE*[18] air injection assembly to obtain a pressurized air-water solution. The key components of dissolved air flotation thickener (DAF) units, as shown in Figure 22.3, are (1) air injection equipment, (2) agitated or unagitated pressurized retention tank, (3) recycle pump, (4) inlet or distribution assembly, (5) sludge scrapers, and (6) an effluent baffle.

The sludge to be thickened is either introduced to the unit at the bottom through a distribution box and blended with a prepressurized effluent stream or the influent stream is saturated with air, pressurized, and then released to the inlet distribution assembly. Total waste stream pressurization may shear flocculent type sludges and seriously reduce process efficiency. Direct saturation and pressurization of the sludge stream is not the preferred mode of operation where primary sludges are to be thickened. Primary sludges often contain stringy material that can clog or "rag-up" the aeration equipment in a pressurized retention tank. Flotation thickening of excess biological solids may use air saturation and pressurization of the waste stream with less possibility of clogging the air addition and dissolution equipment.

The preferred mode of operation from a maintenance standpoint is the use of a recycle stream to serve as the air carrying medium. Referring again to Figure 3.3, the operation of dissolved air flotation (DAF) units which incorporate recycle techniques are as follows. A recycled primary or secondary effluent stream is introduced into a retention tank to dissolve air into the liquid. The retention tank is maintained at a pressure of 45 to 70 psig (3.2 to 4.9 kg/sq cm). Compressed air is either introduced into the retention tank directly or at some point upstream of the retention tank or an aspirator assembly is used to draw air into the stream.

The pressurized air saturated liquid then flows to the distribution or inlet assembly and is released at atmospheric pressure through a back pressure-relief valve. The decrease in pressure causes the air to come out of solution in the form of thousands of minute air bubbles. These bubbles make contact with the influent sludge solids in the distribution box and attach to the solids causing them to rise to the surface. These concentrated solids are then removed from the surface. An effluent baffle is provided to keep the floated solids from going into the effluent. The effluent baffle extends approximately 2 to 3 inches (5.0 to 7.5 cm) above the water surface and 12 to 18 inches (0.3 to 0.45 m) below the surface. Clarified effluent flows under the baffle and leaves the unit through an effluent weir. If air is introduced or aspirated upstream of the retention tank, it is usually done on the suction side of the recycle pump to use the pump as a driving force for dissolving air into the liquid. The main disadvantage associated with introducing air to the suction side of pumps is the possibility of pump *CAVITATION*[19] and the subsequent loss of pump capacity. Systems that add compressed air directly to the retention tank commonly use a float control mechanism to maintain a desired air-liquid balance. A sight glass should be provided to periodically check the level of the air-liquid interface because if the float mechanisms fail, the retention tank may either fill completely with liquid or with air. In either case, the net effect will be a drastic reduction in flotation efficiency.

3.120 Factors Affecting Dissolved Air Flotation

The performance of dissolved air flotation units depends on (1) type of sludge, (2) age of the feed sludge, (3) solids and hydraulic loading, (4) air to solids (A/S) ratio, (5) recycle rate, and (6) sludge blanket depth.

As is the case with gravity thickeners, the type and age of sludge applied to flotation thickeners will affect the overall performance. Primary sludges are generally heavier than excess

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[18] *Aspirate (ASS-per-RATE). Use of a hydraulic device (aspirator or eductor) to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a sump pump.*

[19] *Cavitation (CAV-i-TAY-shun). The formation and collapse of a gas pocket or bubble on the blade of an impeller. The collapse of this gas pocket or bubble drives water into the impeller with a terrific force that can cause pitting on the impeller surface.*

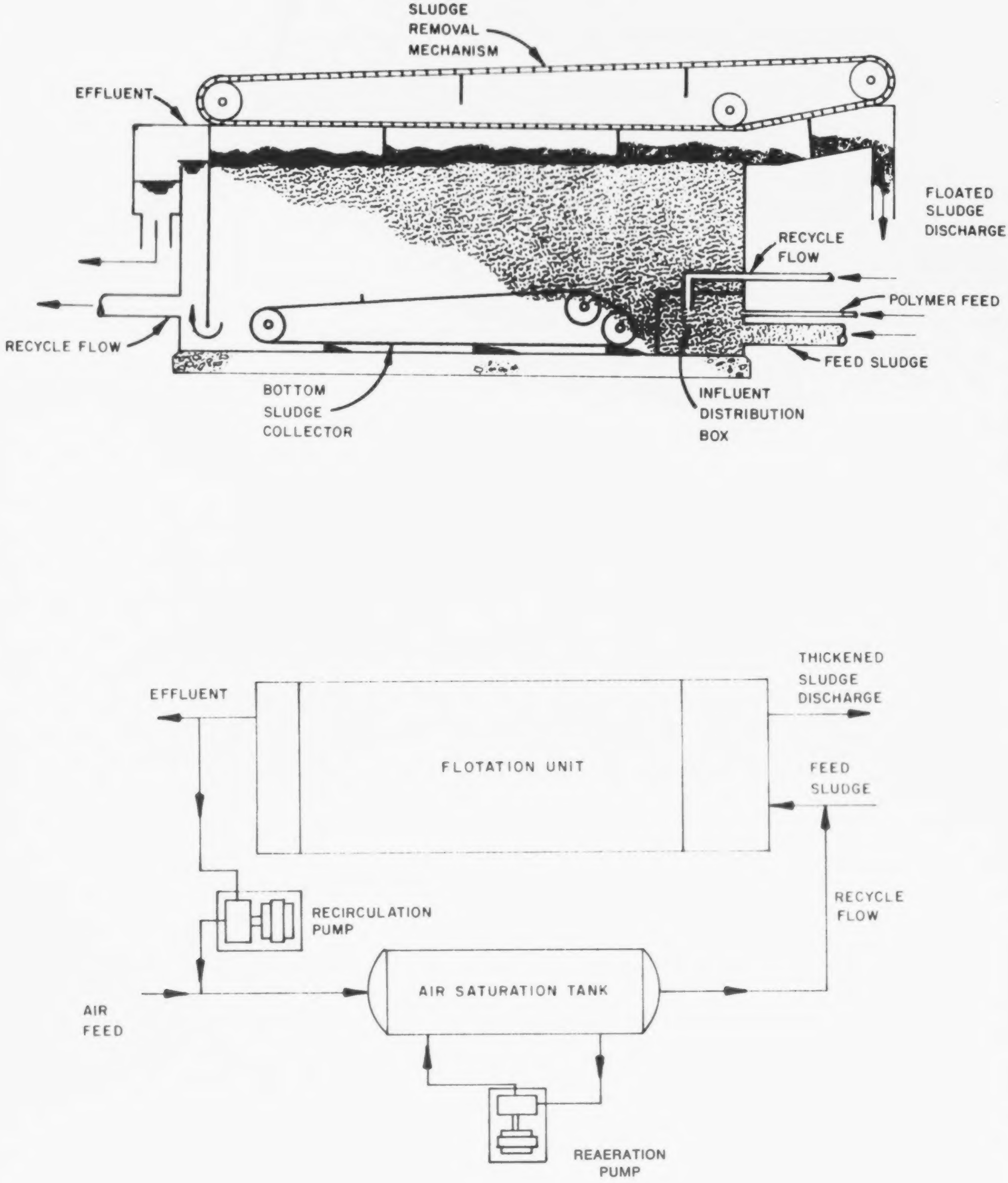
SLUDGE
REMOVAL
MECHANISM
EFFLUENT
FLOATED
SLUDGE
DISCHARGE
RECYCLE
FLOW
POLYMER FEED
RECYCLE FLOW
FEED SLUDGE
BOTTOM
SLUDGE
COLLECTOR
INFLUENT
DISTRIBUTION
BOX
EFFLUENT
THICKENED
SLUDGE
DISCHARGE
FLOTATION UNIT
FEED
SLUDGE
RECIRCULATION
PUMP
RECYCLE
FLOW
AIR SATURATION TANK
AIR
FEED
REAERATION
PUMP

Fig. 3.3 Dissolved air floation thickener

biological sludges and are not as easy to treat by flotation concentration. If enough air is introduced to float the sludge mass, the majority of the primary sludge solids will float to the surface and be removed by the skimming mechanisms. Gritty or heavy primary sludge particles will settle and be deposited on the floor of the flotation unit and provisions should be made to remove these settled solids. If a flotation unit is used for primary sludge thickening, the flotation cell is usually equipped with sludge scrapers to push the settled solids to a collection hopper for periodic removal. Problems will arise when concentrating primary sludges or combinations of primary sludge and waste activated sludge if the flotation chamber is not equipped with bottom sludge scrapers and sludge removal equipment. Solids buildup will result in a decrease in flotation volume and a reduction in thickener efficiency.

Excess biological sludges are easier to treat by flotation thickening than primary sludges because they are generally lighter and thus easier to float. Bottom sludge scrapers should still be incorporated in the design of units used solely for biological sludge because a small fraction of solids will settle. These settled solids will eventually become anaerobic and rise due to gasification. If these solids are deposited at the effluent end of the unit, solids may be carried under the effluent baffle and exit the unit with the effluent.

Sludge age usually does not affect flotation performance as drastically as it affects gravity concentrators. A relatively old sludge has a natural tendency to float due to gasification and this natural buoyancy will have little or no negative effect on the operation of flotation thickeners. However, rising sludge does create problems in primary and final sedimentation processes and should be avoided by controlling the sludge withdrawal rate from these unit processes.

Solids and hydraulic loadings, A/S (air to solids) ratios, recycle rate and sludge blanket depth are normal operational guidelines and are discussed in the following paragraphs.

3.121 Operating Guidelines

The size of dissolved air flotation units is determined by the engineers who design them. The operator has control over A/S ratio, recycle rate and the blanket thickness and can optimize performance by properly adjusting these variables. Before discussing the control variables, the operator should be familiar with determining applied loading rates.

3.1210 Solids and Hydraulic Loadings. Solids hydraulic loadings for flotation units are based on the same calculations used to determine loading rates for gravity thickeners. If either the solids or hydraulic loading becomes excessive, effluent quality declines and thickened sludge concentrations are reduced. The following example shows how to calculate loading rates.

EXAMPLE 10

Given: A dissolved air flotation unit receives 100 gpm of waste activated sludge with a suspended solids concentration of 8,000 mg/*L*. The rectangular flotation unit is 40 feet long and 15 feet wide.

Find: The hydraulic loading (gpm/sq ft) and solids loading (lbs/hr/sq ft).

Solution:

Known		**Unknown**
Flow, GPM	= 100 GPM	1. Hydraulic Loading, gpm/sq ft
Sus Sol, mg/*L*	= 8000 mg/*L* = 0.8%	2. Solids Loading, lbs/hr/sq ft
Flotation Unit		
Length	= 40 ft	
Width	= 15 ft	

1. Determine the hydraulic loading, gpm/sq ft.

$$\begin{aligned}\text{Hydraulic Loading, gpm/sq ft} &= \frac{\text{Flow, GPM}}{\text{Liquid Surface Area, sq ft}}\\ &= \frac{100\text{ gal/min}}{40\text{ ft} \times 15\text{ ft}}\\ &= \frac{100\text{ gal/min}}{600\text{ sq ft}}\\ &= 0.2\text{ gpm/sq ft}\end{aligned}$$

2. Determine the solids loading, lbs/hr/sq ft.

$$\begin{aligned}\text{Solids Loading, lbs/hr/sq ft} &= \frac{\text{Flow, GPM} \times 60\,\frac{\text{min}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%}}{\text{Liquid Surface Area, sq ft}}\\ &= \frac{100\,\frac{\text{gal}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.8\%}{100\%}}{40\text{ ft} \times 15\text{ ft}}\\ &= \frac{400\text{ lbs/hr}}{600\text{ sq ft}}\\ &= 0.67\text{ lbs/hr/sq ft}\end{aligned}$$

3.1211 Air to Solids (A/S) Ratio. The *QUANTITY OF AIR INTRODUCED* and dissolved into the recycle or waste stream *IS CRITICAL* to the operation of flotation thickeners. Enough air has to be added and dissolved to float the sludge solids. The most effective method of accomplishing this is to introduce air into a pressurized retention tank along with the waste stream to be thickened or along with a portion of the thickener effluent stream. Air also can be dissolved in primary or secondary effluent, thus avoiding solids spin around in the DAF unit. *MIXING OF THE RETENTION TANK CONTENTS SHOULD ALSO BE USED TO INCREASE THE AMOUNT OF AIR THAT CAN BE PUT INTO SOLUTION.* In unmixed pressure retention tanks, only about 50 percent of the injected air will dissolve while 90 percent saturation can be obtained by vigorous agitation of the tank contents. As previously discussed, following a short detention time in the pressurized retention tank, the saturated-air-liquid stream is pumped to the inlet side of the flotation unit where it enters a distribution assembly via a back pressure-relief valve. The release of the saturated air stream to atmospheric pressure causes the air to come out of solution in the form of very small bubbles. Thousands of these minute bubbles attach to particles of suspended solids allowing the solids to float to the surface, concentrate and be removed by the sludge skimming mechanism. The more air you have dissolved in the retention tank, the greater the number of minute air bubbles that will be released in the distribution assembly. And, the more bubbles you produce in the distribution assembly, the more efficient your operation will be.

The amount of air supplied to the unit is usually controlled by an air rotameter and compressor assembly which are activated by a liquid level indicator in the retention tank. *THE MOST IMPORTANT OPERATIONAL CONCERN IS TO INSURE*

THAT THE AIR ROTAMETER, COMPRESSOR AND THE FLOAT MECHANISM TO ACTUATE AIR INJECTION ARE IN PROPER WORKING ORDER.

The quantity of air applied to the system is determined according to the following calculations.

EXAMPLE 11

Given: An air rotameter and compressor provide for 10 cubic feet per min *(SCFM)*[20] of air to be injected into a pressurized retention tank.

Find: The pounds of air applied to the unit per hour (lbs/hr).

Solution:

Known	Unknown
Air Flow, SCFM = 10 SCFM	Air Applied, lbs/hr

Calculate the air applied in pounds of air per hour.

$$\begin{aligned}\text{Air Applied, lbs/hr} &= \text{Air Flow}, \frac{\text{cu ft}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times 0.075\,\frac{\text{lb air}}{\text{cu ft air}}\\ &= 10\,\frac{\text{cu ft}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times 0.075\,\frac{\text{lb}}{\text{cu ft}}\\ &= 45\ \text{lbs/hr}\end{aligned}$$

NOTE: The conversion factor of 0.075 pounds of air per cubic foot of air will change with temperature and elevation or barometric pressure.

The ratio between air supplied and the quantity of solids applied to the flotation unit is then the air-to-solids (A/S) ratio. The following example illustrates the determination of air/solids (A/S) ratio.

EXAMPLE 12

Given: A dissolved air flotation unit receives 100 gpm of waste activated sludge at a concentration of 9000 mg/*L* (0.9% solids). Air is supplied at a rate of 5.0 cu ft/min.

Find: The air-to-solids (A/S) ratio.

Solution:

Known		Unknown
Solids Flow, GPM	= 100 GPM	Air-to-Solids (A/S) Ratio
Sl Conc, mg/*L*	= 9000 mg/*L* = 0.9% Solids	
Air, cu ft/min	= 5.0 cu ft/min	

Calculate the air-to-solids (A/S) ratio.

$$\begin{aligned}\frac{\text{Air, lbs}}{\text{Solids, lbs}} &= \frac{\text{Air, cu ft/min} \times 0.075\ \text{lbs/cu ft}}{\text{Solids, GPM} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Conc, \%}}{100\%}}\\ &= \frac{5.0\ \text{cu ft/min} \times 0.075\ \text{lbs/cu ft}}{100\,\frac{\text{gal}}{\text{min}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.9\%}{100\%}}\\ &= \frac{0.375\ \text{lbs air}}{7.5\ \text{lbs solids}}\\ &= 0.05\ \text{lbs air/lb solids}\end{aligned}$$

22.1212 Recycle Rate and Sludge Blanket. Both the rate of effluent recycle and the thickness of the sludge blanket are operational controls available to optimize DAF performance. Typically, the recycle rates of 100 to 200 percent are used. A recycle rate of 100 percent means that for every gallon of influent sludge there is one (1) gallon of DAF effluent recycled to the DAF inlet works.

The following example illustrates the determination of recycle rate.

EXAMPLE 13

Given: A dissolved air flotation unit receives waste activated sludge flow of 50 GPM. The recycle rate is set at 75 GPM.

Find: Percentage of recycle.

Solution:

Known	Unknown
Waste Flow, GPM = 50 GPM	Percentage of recycle.
Recycle Flow, GPM = 75 GPM	

Calculate the percentage of recycle.

$$\begin{aligned}\text{Recycle, \%} &= \frac{\text{Recycle Flow, GPM}}{\text{Waste Flow, GPM}} \times 100\%\\ &= \frac{75\ \text{GPM}}{50\ \text{GPM}} \times 100\%\\ &= 150\%\end{aligned}$$

The optimum recycle rate for a particular unit will vary from one treatment plant to the next and it is impossible to define that rate for every application. The important point is that the recycle stream carries the air to the inlet of the unit. Obviously, as the rate of recycle increases, the potential to carry more air to the inlet also increases. The term "potential" is used here because the recycle rate and the quantity of air dissolved and released in the inlet assembly are dependent on one another by virtue of what happens in the retention tank. DAF recycle pumps are usually centrifugal pumps which means that as the pressure upstream (retention tank) increases, the output (flow) decreases. Therefore, the rate of recycle is directly dependent on the pressure maintained within the retention tank. As stated previously, retention tank pressures of 45 to 70 psi (3.2 to 4.9 kg/sq cm) are commonly used. As the pressure within the retention tank is increased or decreased by closing or opening the back pressure-relief valve, the recycle rate will decrease or increase. The optimum recycle rate and retention tank pressure are usually determined by experimentation.

The thickness of the floating sludge blanket can be varied by increasing or decreasing the speed of the surface sludge scrapers. Increasing the sludge scrapers speed usually tends to thin out the floated sludge while decreasing the scrapers speed will generally result in a more concentrated sludge.

3.122 Normal Operating Procedures

Typically, the flow through the thickener is continuous and should be set as constant as possible. Monitoring of the influent, effluent, and float sludge streams should be done at least once per shift and composite samples should be taken for later laboratory analysis.

Under normal operating conditions, the effluent stream should be relatively free of solids (less than 100 mg/*L* suspended solids) and will resemble secondary effluent. The float solids will have a consistency resembling that of cottage cheese. The depth of the float solids should extend approximately 6 to 8 inches (15 to 20 cm) below the surface. The surface farthest from the float solids collection and the discharge point should be scraped clean of floating solids with each pass of the sludge collection scrapers. If the sludge blanket is allowed to build up (too thick) and drop too far below the surface, thickened (floated) solids will be carried under the effluent baffle and contaminate the effluent.

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[20] *SCFM. Cubic Feet of air per Minute at Standard conditions of temperature, pressure and humidity.*

Normal start-up and shutdown procedures are outlined below:

Start-Up

— Open the inlet and discharge valves on the recycle pump and turn on the recycle pump only when thickener is full.

— Adjust the retention tank pressure to the desired pressure (45 to 70 psig or 3.2 to 4.9 kg/sq cm) by opening or closing the pressure regulating valve.

— Open the inlet and discharge valves on the reaeration pump and turn on the reaeration pump. If a mechanical mixer is used instead of a reaeration pump, turn on the mixer in the retention tank. Mixing in the retention tank may be accomplished by methods other than the use of mechanical mixers.

— Open the appropriate air injection valves and turn on the air compressor.

— Open the appropriate chemical addition valves and turn on the chemical pump if chemicals are used.

— Open the inlet and discharge valves on the sludge feed pump and start the feed pump.

— Allow floated sludge mat to build up, then turn on sludge collection scrapers.

If the thickener is not operated in a continuous mode and daily or frequent shutdowns are required, the following procedures should be followed:

Shutdown

— Turn off the sludge inlet pump and close the appropriate valves.

— Turn off the chemical pump and close appropriate valves.

— Turn on the fresh water supply to the unit *AND ALLOW IT TO RUN ON FRESH WATER UNTIL THE SURFACE IS FREE OF FLOATING SLUDGE.*

— Turn off the air compressor and close appropriate air valves.

— Turn off the reaeration and recycle pumps and close appropriate valves.

— Turn off the sludge collectors.

— Hose down and clean up as required.

3.123 Typical Performance

Typical operating guidelines as well as thickened sludge concentration and suspended solids removals for waste activated sludge are presented in Table 3.4

TABLE 3.4 OPERATIONAL AND PERFORMANCE GUIDELINES FOR FLOTATION THICKENERS

	Without Polymer Addition	With Polymer Addition
Solids Loading, lbs/hr/sq ft*	0.4 - 1	1 - 2
Hydraulic Loading, GPM/sq ft**	0.5 - 1.5	0.5 - 2.0
Recycle, %	100 - 200	100 - 200
Air/Solids, lb/lb	0.01 - 0.10	0.01 - 0.10
Minimum Influent Solids Concentration, mg/*L*	5000	5000
Float Solids Concentration, %	2 - 4	3 - 5
Solids Recovery, %	50 - 90	90 - 98

* lbs/hr/sq ft × 4.883 = kg/hr/sq m
** GPM/sq ft × 0.679 = *L*/sec/sq m

The determination of solids recovery in the operation of the DAF unit is based on laboratory analysis and the following calculations.

EXAMPLE 14

Given: A 100-foot diameter dissolved air flotation unit receives 750 GPM of waste activated sludge at a concentration of 0.75% (7500 mg/*L*) sludge solids. The effluent contains 50 mg/*L* of suspended solids. The float or thickened sludge is at a concentration of 3.3 percent.

Find: The solids removal efficiency (%) and the concentration factor (cf).

Solution:

Known	Unknown
Dissolved Air Flotation Unit	1. Solids Removal Efficiency, %
Infl Solids, mg/*L* = 7500 mg/*L*	2. Concentration Factor (cf)
or = 0.75%	
Effl Solids, mg/*L* = 50 mg/*L*	
Effl Sludge, % = 3.3% (Thickened Sludge)	

1. Determine the solids removal efficiency, %.

$$\text{Solids Removal Efficiency, \%} = \frac{(\text{Inf Solids, mg}/L - \text{Effl Solids, mg}/L)\ 100\%}{\text{Infl Solids, mg}/L}$$

$$= \frac{(7500\ \text{mg}/L - 50\ \text{mg}/L)\ 100\%}{7500\ \text{mg}/L}$$

$$= 99.3\%$$

2. Calculate the concentration factor (cf) for the thickened sludge.

$$\text{Concentration Factor, (cf)} = \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}}$$

$$= \frac{3.3\%}{0.75\%}$$

$$= 4.4$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 249 and 250.

3.12A List the main components of dissolved air flotation (DAF) systems.

3.12B Discuss the function of the distribution box, the retention tank and the effluent baffle.

3.12C Why should a sight glass be provided on the retention tank?

3.12D List the factors that affect the performance of DAF thickeners.

3.12E What effect does sludge age have on DAF thickeners?

3.12F Determine the hydraulic loading (gpd/sq ft) for a 20-foot diameter DAF unit. The influent flow is 100 GPM.

3.12G For the above problem, determine the solids loading, A/S ratio and recycle flow rate (GPM), if the influent sludge has a suspended solids concentration of 0.75% (7500 mg/*L*), and is supplied at a rate of 2.5 cu ft/min. Air is supplied at a rate of 0.75 cu ft/min and a recycle ratio of 100 percent is required.

3.12H Determine the suspended solids removal efficiency (%) and the concentration factor (cf) if a DAF unit receives an influent sludge at 1.0 percent (10,000 mg/*L*) suspended solids. The effluent is at 50 mg/*L* suspended solids and the float or thickened sludge is at a concentration of 3.8 percent.

3.124 Troubleshooting

VISUAL INSPECTION of the dissolved air flotation unit in conjunction with a working knowledge of the operating techniques is the operator's biggest asset in assuring efficient operation. The specific areas that the operator should be concerned with are: (1) effluent quality, and (2) thickened sludge (float) characteristics. The effluent from DAF units should be relatively clear (less than 100 mg/*L* suspended solids). Well operated units should produce effluents equivalent in appearance to secondary clarifier effluent. If an unusually high amount of suspended solids are exiting the unit with the effluent, the problem may be related to: (1) sludge blanket thickness, (2) chemical conditioning, (3) A/S ratio, (4) recycle rate, (5) solids and/or hydraulic loading or any combination of the above.

If the float solids appear to be well flocculated and concentrated (resembling cottage cheese), the speed of the sludge scrapers should be increased. Poor effluent quality in conjunction with a concentrated float sludge usually results from allowing the sludge blanket to develop too far below the surface. When this happens, the undermost portions of the blanket will break off and be carried under the effluent baffle. Increasing the sludge collector speed will result in a decrease in blanket thickness and prevent solids from flowing under the baffle.

If the scrapers are already operating at full speed and the blanket level is below the effluent baffle, the unit is probably overloaded with regard to solids. In this case, the influent flow rate and concentration should be checked and the flow rate should be decreased, if possible.

High solids carryover with the effluent, in conjunction with lower than normal float solids concentrations, usually indicate that problems exist with the air system, chemical conditioning system and/or the loading rates. The operator should systematically check the retention tank pressure and sight glass, the recycle pump, the air compressor assembly, the re-aeration pump, the chemical conditioning equipment, and the influent flow.

Equipment malfunctions are quickly revealed by checking the retention tank pressure and the sight glass. Higher than desired pressures will result in decreased recycle rates and the back pressure-relief valve should be opened somewhat to decrease the pressure and increase the recycle rate. Lower than normal pressures will result in higher recycle rates. In this case, the pressure-relief valve should be closed somewhat to decrease the recycle rate, and allow more time for air to dissolve in the retention tank.

Malfunctions in the retention tank liquid level indicator and air compressor activation assembly will also cause drastic decreases in flotation efficiency. The liquid level rated on the sight glass is the best indicator of this problem.

If the liquid level in the retention tank is lower or higher than normal, either the float mechanism to activate the air inlet valve or control is malfunctioning or the air compressor and solenoid valves are not operating correctly. If the liquid level in the retention tank is not at the desired level, the operator should shut the DAF unit off, open the hatch on the retention tank, and clean the liquid level indicator probes.

If everything (air, recycle, and retention pressure) seems to be in proper order, but the DAF effluent is still high in solids and the float solids are at a low concentration, the operator should check the retention tank mixer (re-aeration pump), the chemical conditioning system and the loading rates.

If chemical conditioners are used, they must be prepared properly and applied at the desired dosage. Chemical conditioning is covered in Section 3.3. The operator should be fully aware that proper operation of the chemical conditioning system will not only greatly help the performance of the DAF, but it should be carefully watched and calibrated because of the high cost of chemicals.

If all the equipment is operating properly and the problem still exists, the operator should check the hydraulic and solids loading according to Example 10 and adjust flow rates as required.

Table 3.5 summarizes problems that may arise and the corrective measures that might be taken.

TABLE 3.5 TROUBLESHOOTING DISSOLVED AIR FLOTATION

Operational Problem	Possible Causes	Check or Monitor	Possible Solutions
1. Solids carryover with effluent but good float concentration	1. Float blanket too thick	1.a. Flight speed b. Solids loading	1.a. Increase flight speed b. Lower flow rate to unit if possible
2. Good effluent quality but float sludge thin (dilute)	2. Float blanket too thin	2.a. Flight speed b. Solids loading	2.a. Decrease flight speed b. Increase flow rate if possible
3. Poor effluent quality and thin (dilute) float sludge	3.a. A/S low b. Pressure too low or too high c. Recycle pump inoperative d. Reaeration pump inoperative e. Chemical addition inadequate f. Loading excessive	3.a. —Air rate —Compressor b. Pressure gage c. Pressure gage and pump d. Pump pressure e. Chemical system f. Loading rates	3.a. -Increase air input -Repair and/or turn on compressor b. Open or close valve c. Turn on recycle pump d. Turn on re-aeration pump e. Increase chemical dosage f. Lower flow rate

QUESTION

Write your answers in a notebook and then compare your answers with those on page 250.

3.12I On a routine check of a dissolved air flotation unit, the operator notices high suspended solids in the effluent and a thinner than normal sludge. *DISCUSS* the possible causes and solution to the problem.

3.13 Centrifuge Thickeners

Centrifugal thickening of wastewater sludge results from sedimentation and high centrifugal forces. Sludge is fed at a constant feed rate to a rotating bowl. Solids are separated from the liquid phase by virtue of the centrifugal forces and are forced to the bowl wall and compacted. The liquid and fine solids *(CENTRATE)*[21] exit the unit through the effluent line.

Three centrifuge designs are commonly installed today. They are (1) basket centrifuges, (2) scroll centrifuges, and (3) disc-nozzle type centrifuges. The mechanical operation of the three centrifuges varies significantly and separate descriptions of each will follow.

BASKET CENTRIFUGE. The basket centrifuge is a solid bowl which rotates along a vertical axis and operates in a batch manner. A schematic of a typical basket centrifuge is shown in Figure 3.4. Feed material is transported by a pipe through the top and is introduced at the bottom of the unit. This sludge is accelerated radially outward to the basket wall by centrifugal force. Cake continually builds up within the basket until the quality of the centrate, which overflows a weir at the top of the unit, begins to deteriorate. At that point, feed to the unit is stopped and a nozzle skimmer enters the bowl to remove the innermost and wettest portion of the retained solids. The inner solids are generally too wet for conveyor belt transport through the system. Upon completion of the skimming sequence, which takes about one-half minute, deceleration of the bowl takes place followed by knife or plow insertion. As the knife moves toward the bowl wall, retained solids are scraped out and fall through the bottom of the basket for conveyance to a discharge point as cake. Upon retraction of the knife, the solids discharge cycle is completed.

When basket centrifuges are used as thickening devices, full-depth skimming is commonly practiced with the nozzle skimmer while the basket is revolving at full speed, and the deceleration and knife insertion sequences are eliminated from the operation.

SCROLL CENTRIFUGE. The scroll centrifuge is a solid bowl which rotates along a horizontal axis and operates in a continuous manner. A schematic of this type of centrifuge is shown in Figures 3.5 and 3.6. The newest design in scroll centrifuges is a tapered bowl which employs an inner scroll to evenly distribute the feed sludge. Sludge is fed to the unit through a stationary tube along the center line of the inner screw which accelerates the sludge and minimizes turbulence. Sludge passes through ports in the inner conveyor shaft and is distributed to the periphery (outer edge) of the bowl. Solids settled through the liquid pool in the separating chamber are compacted by centrifugal force against the bowl and are conveyed by the outer screw conveyor to the discharge point. Separated liquid (centrate) is discharged continuously over an adjustable weir.

DISC-NOZZLE CENTRIFUGE. The disc-nozzle centrifuge is a solid bowl which rotates along a vertical axis and operates in a continuous manner. A schematic of the centrifuge is shown in Figure 3.7. Feed material is introduced at the top of the unit and flows through a set of some 50 conical discs which are used for stratification (separation into layers) of the waste stream to be clarified. The discs are fitted quite closely together and centrifugal force is applied to the relatively thin film of liquor and solids between the discs. This force throws the denser solid material to the wall of the centrifuge bowl where it is subjected to additional centrifugal force and concentrated before it is discharged through nozzles located on the periphery. Clear liquid continuously flows over a weir at the top of the bowl and exits via the centrate line. The bowl is equipped with twelve nozzle openings, but various numbers and sizes of discharge nozzles can be used depending on feed liquor characteristics and the desired results. The number and size of discharge nozzles used directly controls final sludge concentration for any given feed condition.

3.130 Factors Affecting Centrifuge Thickeners

The performance of centrifugal thickeners depends on (1) type of sludge, (2) age of the feed sludge, (3) solids and hydraulic loading, (4) bowl speed and resulting gravitational ("g") forces, (5) pool depth and differential scroll speed for scroll centrifuges and (6) size and number of nozzles for disc centrifuges.

Centrifuges are not commonly used to thicken primary sludges because each of the three designs have sludge inlet assemblies that are highly subject to clogging. For this reason, there will be no discussion of centrifugal thickening of primary sludge.

Secondary sludges are more suited to centrifugal thickening because of their lack of stringy and bulky material and the potential for plugging is minimal. Centrifuges are less affected

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[21] *Centrate. The water leaving a centrifuge after most of the solids have been removed.*

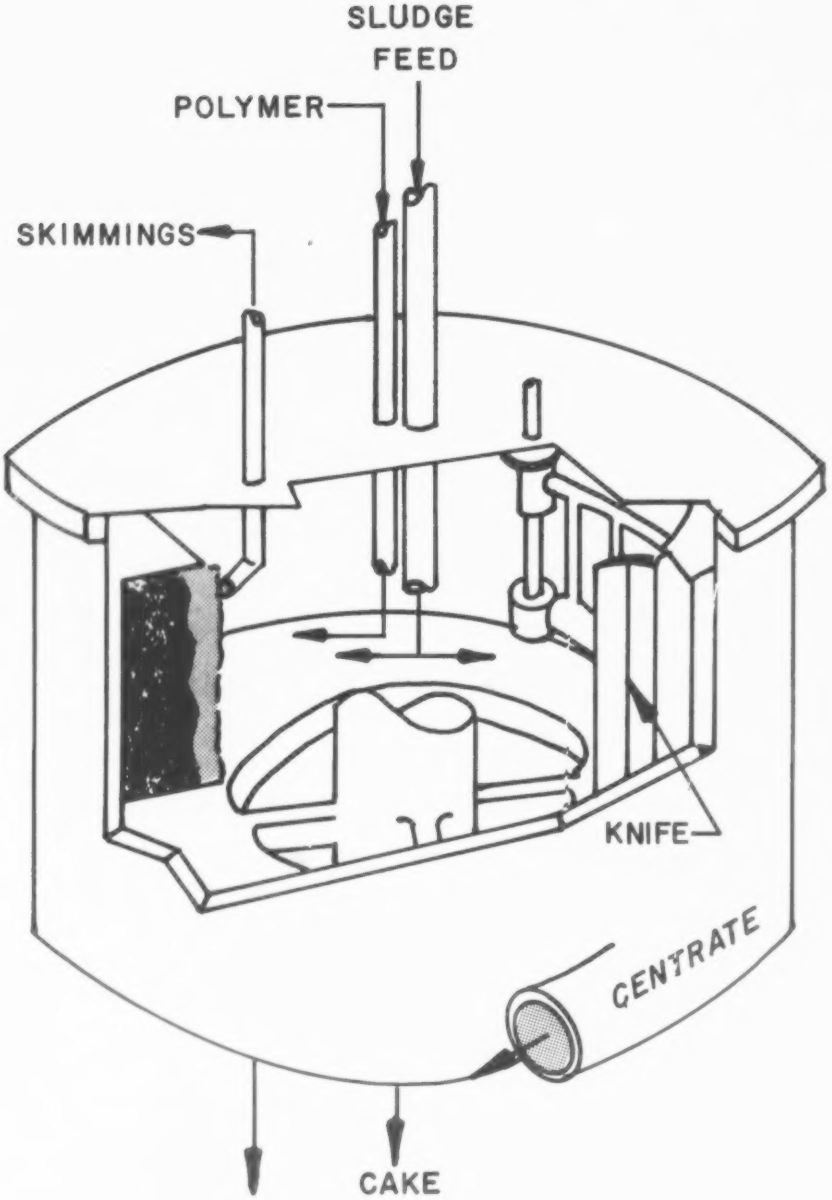
SLUDGE FEED
POLYMER
SKIMMINGS
KNIFE
CENTRATE
CAKE

Fig. 3.4 Basket Centrifuge

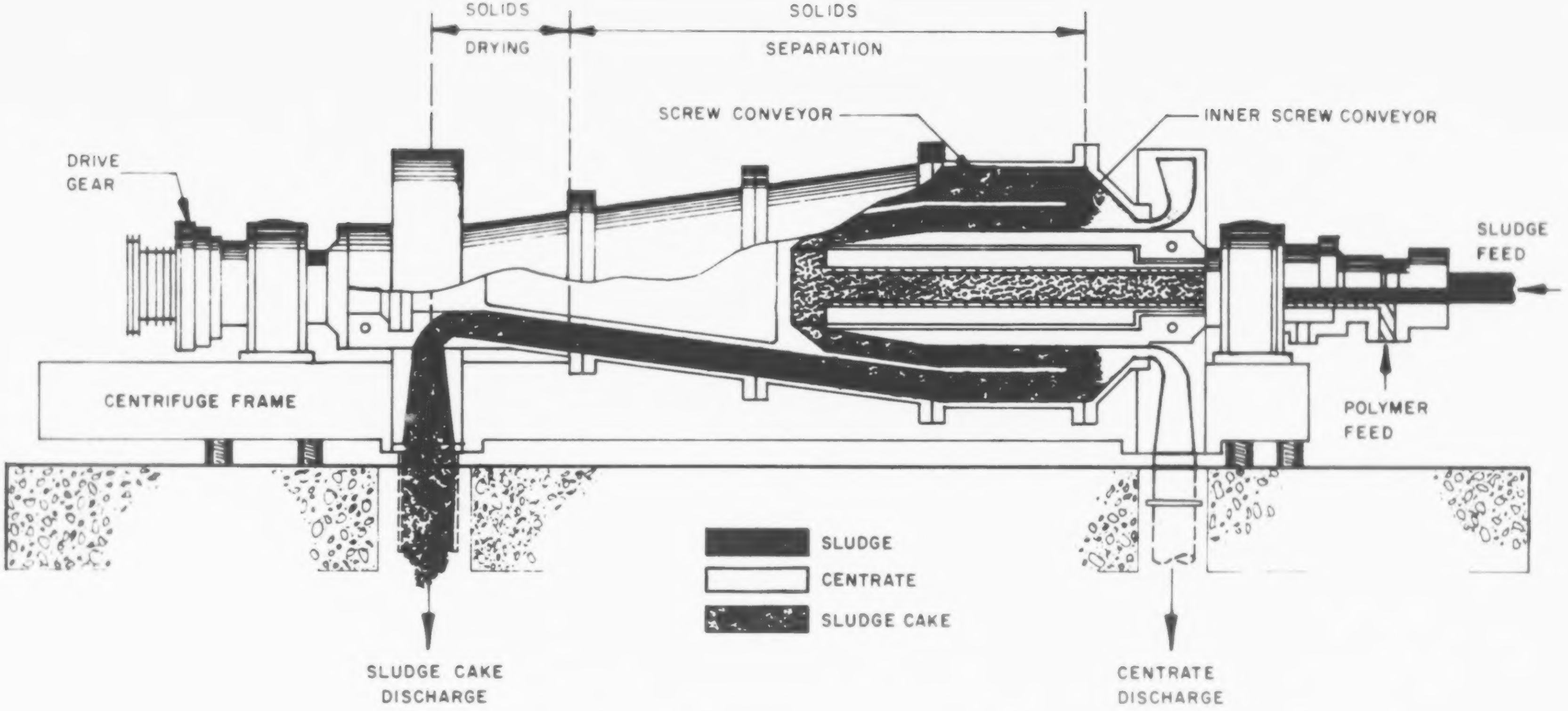
SOLIDS
DRYING
SOLIDS
SEPARATION
SCREW CONVEYOR
INNER SCREW CONVEYOR
DRIVE GEAR
SLUDGE FEED
CENTRIFUGE FRAME
POLYMER FEED
SLUDGE
CENTRATE
SLUDGE CAKE
SLUDGE CAKE DISCHARGE
CENTRATE DISCHARGE

Fig. 3.5 *Scroll centrifuge (horizontal-tapered bowl)*

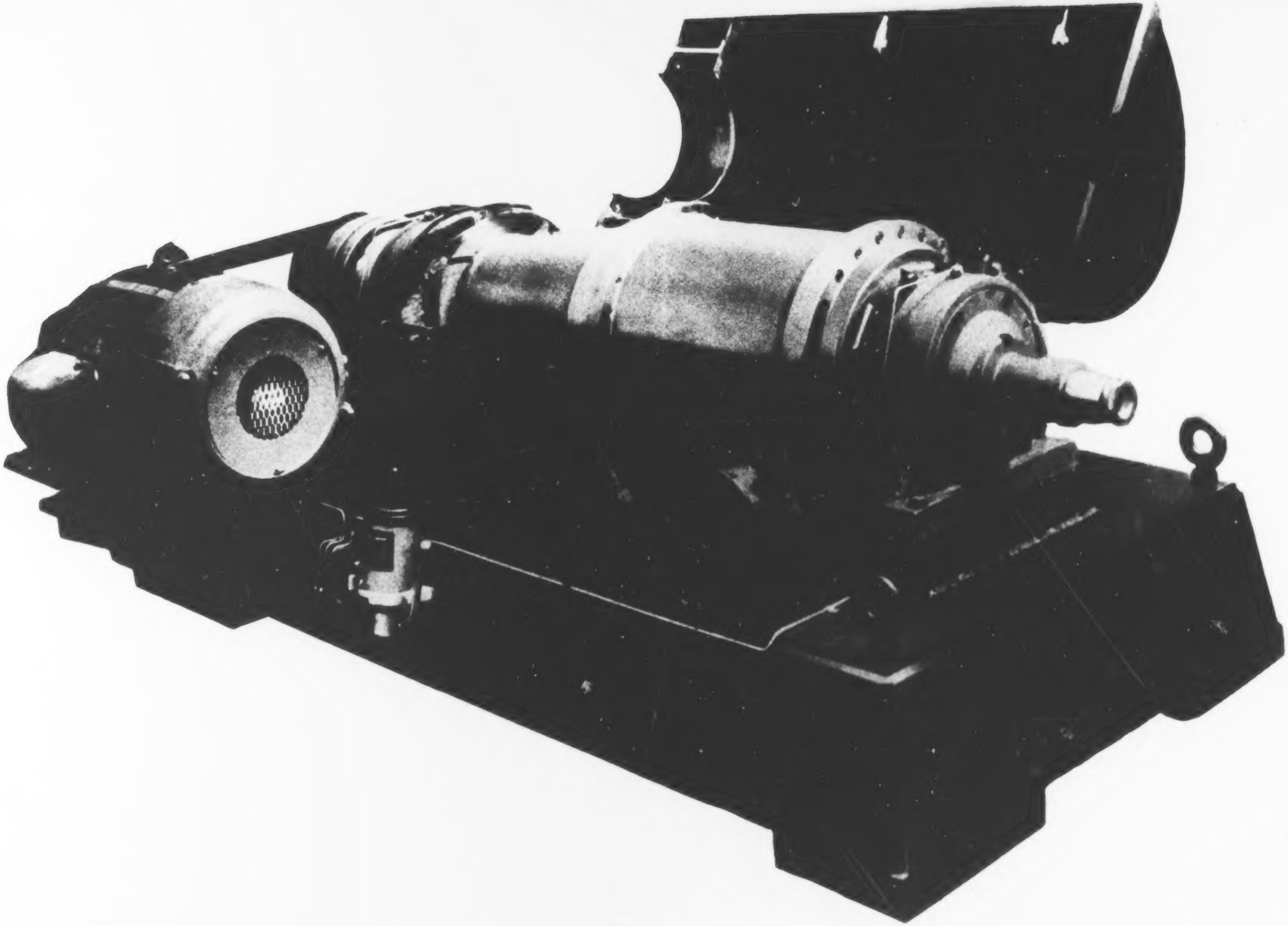

Fig. 3.6 Photo of scroll centrifuge

(Permission of Dorr-Oliver Incorporated)

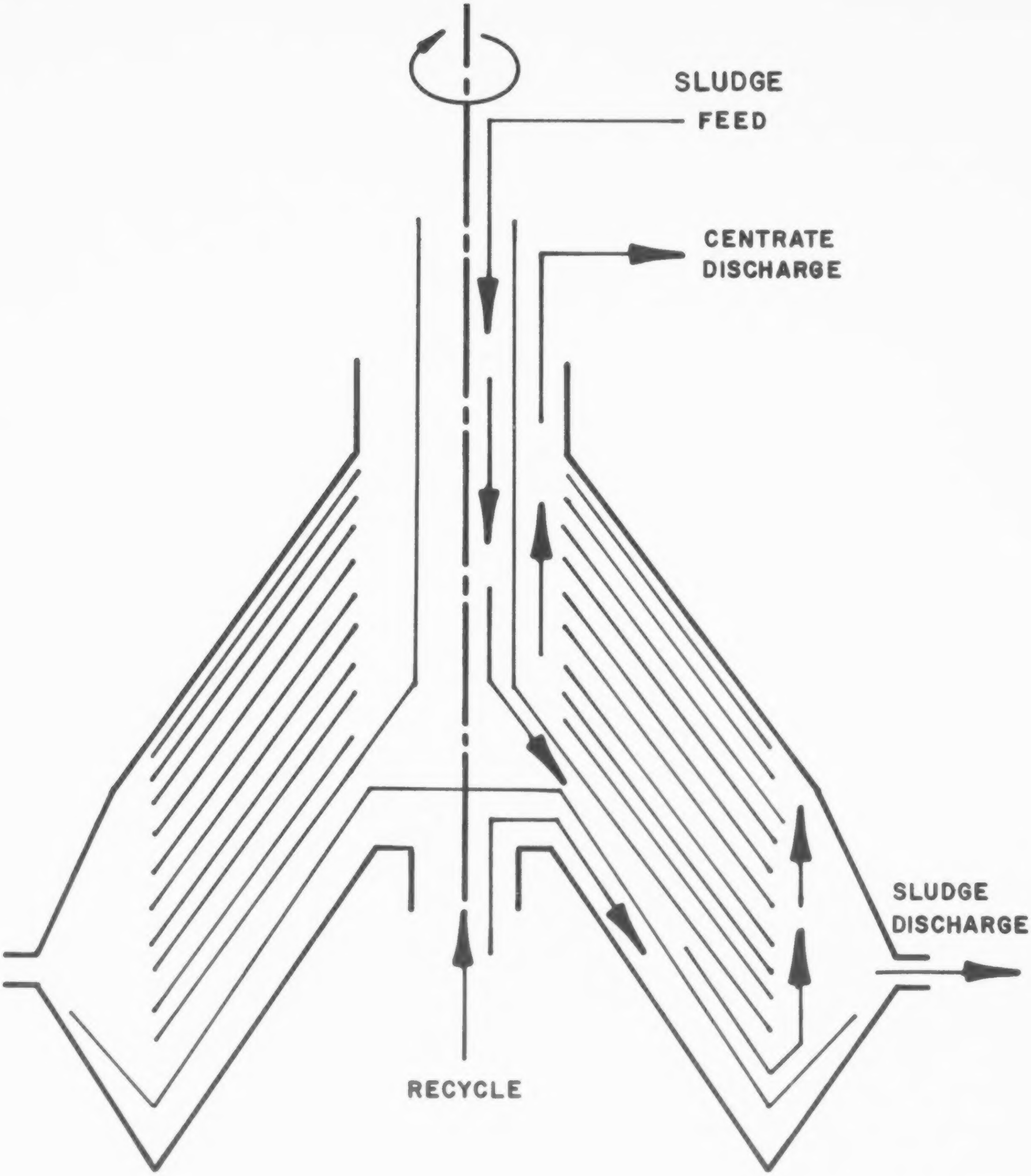
SLUDGE FEED
CENTRATE DISCHARGE
SLUDGE DISCHARGE
RECYCLE

Fig. 3.7 Disc centrifuge

by sludge characteristics such as age of sludge and bulking or rising conditions due to the high centrifugal forces developed. Usually, centrifugal forces of 600 to 1400 "g's" or 600 to 1400 times the force of gravity are developed and fluctuations in sludge thickening characteristics can generally be overcome. However, in all cases, if the sludge is fresh and exhibits good settling characteristics, it would more readily be thickened than an old sludge. Every attempt should be made, regardless of the thickening system used, to feed a consistent and fresh sludge to the thickening facility. Solids and hydraulic loading, bowl speed, differential scroll speed, and nozzle sizes will be discussed in the following paragraphs.

3.131 Operating Guidelines

The physical size and number of centrifugal thickeners needed depends on the anticipated sludge volume and its dewatering properties. For a specific plant, the operator usually has a variety of operational controls to optimize centrifuge performance. Prior to a discussion of these control strategies, the operator should be familiar with determining hydraulic and solids loadings.

3.1310 Hydraulic and Solids Loadings. Unlike gravity and flotation thickeners, the loading rates for centrifuges are not related to unit areas (gpm/sq ft or gpd/sq ft). The accepted loading unit terminology for centrifuge loadings are gal/hr/unit or lbs/hr/unit. This type of terminology is used because of the various sizes available from different manufacturers and the variations in design from one unit to the next unit.

The loading rates of scroll centrifuges and disc centrifuges are straightforward and illustrated in the following sample calculations.

EXAMPLE 15

Given: A scroll centrifuge was selected to thicken 120,000 GPD of waste activated sludge with an initial sludge solids (SS) concentration of 0.80 percent (8,000 mg/*L*).

Find: 1. The hydraulic load (gal/hr).
2. The solids load (lb SS/hr).

Solution:

Known		Unknown
Scroll Centrifuge		1. Hydraulic Load, gal/hr
Flow, GPD	= 120,000 GPD	
Sludge Solids, mg/*L*	= 8,000 mg/*L*	2. Solids Load, lbs Sl Sol/hr
, %	= 0.80%	

1. Determine the hydraulic load in gallons per hour.

$$\text{Hydraulic Load, gal/hr} = \frac{\text{Flow, GPD}}{24\text{ hr/day}}$$

$$= \frac{120{,}000\text{ gal/day}}{24\text{ hr/day}}$$

$$= 5{,}000\text{ gal/hr}$$

2. Calculate the solids load in pounds of sludge solids per hour.

$$\text{Solids Load, lbs/hr} = \text{Flow, gal/hr} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}$$

$$= 5000\,\frac{\text{gal}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.80\%}{100\%}$$

$$= 334\text{ lbs/hr}$$

These same calculations would apply for disc-nozzle centrifuges. The determination of loading rates for basket centrifuges is more complicated because they operate in a batch manner and the down time required to remove the thickened solids must be incorporated in the loading calculation as follows.

EXAMPLE 16

Given: A basket centrifuge is fed 50 GPM of waste activated sludge at a sludge solids concentration of 0.8%. The basket run time is 20 minutes for the unit to fill completely with solids. After the unit is full, the solids are skimmed out. The skimming operation takes 1½ minutes.

Find: 1. Hydraulic Load (gal/hr)
2. Solids Load (lbs/hr)

Solution:

Known		Unknown
Basket Centrifuge		1. Hydraulic Load, gal/hr
Flow, GPM	= 50 GPM	2. Solids Load, lbs/hr
Sludge Solids, %	= 0.8%	
Run Time, min	= 20 min	
Skimming Time, min	= 1.5 min	

KNOWN
UNKNOWN

1. Determine the hydraulic load in gallons per hour.

$$\text{Hydraulic Load, gal/hr} = \text{Flow, }\frac{\text{gal}}{\text{min}} \times \frac{\text{Run Time, min}}{(\text{Run Time, min} + \text{Skm Time, min})} \times 60\,\frac{\text{min}}{\text{hr}}$$

$$= 50\,\frac{\text{gal}}{\text{min}} \times \frac{20\text{ min}}{(20\text{ min} + 1.5\text{ min})} \times 60\,\frac{\text{min}}{\text{hr}}$$

$$= 2{,}790\text{ gal/hr}$$

If the unit were fed continuously at a rate of 50 GPM, the hydraulic loading rate would be 3,000 gal/hr (50 gal/min × 60 min/hr).

2. Calculate the solids load in pounds of sludge solids per hour.

$$\text{Solids Load, lbs/hr} = \text{Flow, }\frac{\text{gal}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}$$

$$= 2790\,\frac{\text{gal}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{0.8\%}{100\%}$$

$$= 186\text{ lbs/hr}$$

3.1311 Bowl Speed. Regardless of the type of centrifuge (basket, scroll, or disc) used, increasing the bowl speed (RPM) will result in higher gravitational forces and thicker sludge concentration. This is because gravitational forces are directly proportional to the bowl diameter and revolutions per minute. For a given machine, the bowl diameter is fixed and cannot be changed. If more or less "g" force is desired, the bowl speed should be increased or decreased but *IN NO WAY SHOULD THE BOWL BE OPERATED AT SPEEDS OUT OF THE MANUFACTURER'S RECOMMENDED RANGE.* Operation out of the recommended range can lead to bearing failures and costly repairs.

3.1312 Feed Time. This section deals with the basket-type batch operated centrifuges only. The actual feed time (run time) for basket centrifuges will depend on the influent sludge solids concentration (% SS), the flow rate (GPM), and the average concentration of the solids retained in the basket. The solids storage volume within a basket is fixed. If the feed is shut off prior to filling the storage area with solids, the portion of retained sludge farthest from the basket wall will be extremely wet. The net effect of not filling the basket completely with solids is an overall decrease in the cake solids concentration because large volumes of water are carried out during the skimming sequence.

Conversely, if the feed time exceeds the time required to fill the storage area with solids, the effluent quality will decrease drastically after the bowl is full. This is because once the basket is filled with solids, no more storage area is available for additional incoming solids.

The following example illustrates the feed time required to fill a 48-inch diameter basket centrifuge with concentrated solids. *ALL 48-INCH DIAMETER BASKETS HAVE SOLIDS STORAGE VOLUMES OF APPROXIMATELY 16 CUBIC FEET.*

EXAMPLE 7

Given: A 48-inch diameter basket is used to thicken waste activated sludge at a concentration of 0.75 percent sludge solids. The applied flow rate is 50 GPM and the average concentration of solids within the basket is 7.0 percent.

Find: The time required to fill the storage volume with thickened sludge.

Solution:

Known	Unknown
48-inch diameter basket centrifuge	1. Time required to fill storage volume, min

Flow, GPM = 50 GPM

Infl Solids, % = 0.75%

Basket Solids, % = 7.0%

Solids Storage Vol, cu ft = 16 cu ft

1. Calculate the amount of stored solids in pounds.

$$\text{Solids, lbs} = \text{Storage Vol, cu ft} \times 62.4\ \frac{\text{lbs}}{\text{cu ft}} \times \frac{\text{Bkt Sol, \%}}{100\%}$$

$$= 16\ \text{cu ft} \times 62.4\ \frac{\text{lbs}}{\text{cu ft}} \times \frac{7.0\%}{100\%}$$

$$= 70\ \text{lbs}$$

Therefore, under these conditions the centrifuge could store 70 pounds of dry solids.

2. Determine the time required to fill the storage volume or the feed time in minutes.

$$\text{Feed time, min} = \frac{\text{Stored Solids, lbs}}{\text{Flow, GPM} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{\text{Inf Sol, \%}}{100\%}}$$

$$= \frac{70\ \text{lbs}}{50\ \frac{\text{gal}}{\text{min}} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{0.75\%}{100\%}}$$

$$= \frac{70\ \text{lbs}}{3.13\ \text{lbs/min}}$$

$$= 22\ \text{minutes}$$

For the conditions given in the above example, feed times less than 22 minutes will result in wetter discharge solids and feed times greater than 22 minutes will result in poorer effluent quality.

3.1313 Differential Scroll Speed and Pool Depth. This section deals with scroll-type centrifuges only. In addition to being able to adjust the bowl speed, the operator can adjust the differential or relative scroll speed and the liquid depth (pool) within the bowl. As previously discussed, scroll centrifuges have an inner screw (scroll) which rotates at a different speed than the bowl. The difference between the bowl speed and the speed of the inner screw is termed the "differential" (relative) scroll speed. As the differential scroll speed is increased, the solids that are compacted on the bowl wall are conveyed out of the centrifuge at a faster rate, resulting in a decrease in the concentration of these solids. Lower concentrations result because as the solids are moved out at a faster rate, they are subjected to centrifugal forces for shorter periods of time. Likewise, as the relative scroll speed is decreased, the solids at the bowl wall are moved out at a slower rate and are more compact because they are subjected to the centrifugal forces for longer times.

The liquid depth (pool depth) within the bowl can be varied by adjusting and/or changing the effluent weirs. As the bowl depth is increased, the effluent quality will also increase because the liquid level and consequently the hydraulic detention time within the bowl increases. Longer retention times result in increased suspended solids capture because these solids have a better opportunity to be thrown to the bowl wall. Conversely, as the pool depth decreases, the suspended solids removal and effluent quality also decrease due to shorter detention times within the bowl. However, in regard to cake solids, changing the pool depth has just the opposite effect. As the pool depth is increased, solids recovery increases but the cake solids get wetter. As the pool depth is decreased and solids recovery decreases, the cake solids get dryer. Thus the operator must adjust the pool depth to get the recovery and cake solids desired, realizing that a high recovery will usually result in the wettest cakes, while dry cakes are normally accompanied with lower solids recovery.

3.1314 Nozzle Size and Number. This section deals only with disc-nozzle type centrifuges. The degree of sludge thickening can be controlled somewhat by increasing or decreasing both the number of nozzles and nozzle openings. Nozzles are located at the periphery (outer edge) of the disc centrifuge bowl and are used to discharge the thickened sludge from the unit. If the size of the nozzles is increased, the dryness of the compacted sludge will decrease because the sludge will exit the unit at a faster rate and will not concentrate to its highest degree. This principle is much like that of the scroll speed where increasing differential scroll speeds result in wetter sludge. If the nozzle openings are reduced and/or the number of nozzles is decreased, the sludge will remain subjected to centrifugal forces for longer times and will dry or become thicker.

3.132 Normal Operating Procedures

Typically, the flow through centrifuges is continuous and should be set as constant as possible. Even though the basket centrifuge is a batch process, the flow rate during the feeding time should be as constant as possible. Routine monitoring of the influent, effluent, and thickened sludge streams should be done at least once per shift and samples collected for pertinent solids analysis. Normal start-up and shutdown procedures for the three centrifuge types varies and each is outlined below.

BASKET CENTRIFUGE

— Retract the skimmer and plow.

— Turn on the drive motor.

— When the centrifuge reaches approximately 80 percent full speed, open appropriate chemical and sludge inlet valves and turn on the pumps.

— When the centrate "breaks" (high solids in effluent), turn off the sludge and chemical pumps.

— While the machine is operating at full speed, activate the skimmer to advance towards the wall and remove solids.

— If full-depth skimming cannot be used (sludge is too thick), retract the skimmer and push and deceleration button.

— When the bowl is rotating at approximately 50 to 70 RPM, activate the plow.

— After all the solids are removed, retract the plow, accelerate the bowl and proceed as above.

For any prolonged machine shutdown, fresh water should be pumped into the bowl while the knife is inserted to clean the wall. Following clean-out, the knife is retracted and the drive motor turned off.

SCROLL CENTRIFUGE

— Turn on drive motor.

— When the bowl is at full speed, open appropriate chemical and sludge valves and turn on the respective pumps.

— Adjust differential (relative) scroll speed as required.

— Flush centrifuge after each use to prevent solids from caking on inside of bowl.

For prolonged machine shutdown, the feed and chemical pumps are turned off and fresh water is introduced into the unit for approximately 20 to 30 minutes. The drive motor is then turned off.

DISC NOZZLE CENTRIFUGE

— Turn on drive motor.

— Activate the pre-screens.

— When the unit is at full speed, open appropriate chemical and sludge valves and turn on the respective pumps.

For prolonged machine shutdown, the feed and chemical pumps are turned off and water is introduced into the centrifuge for 20 to 30 minutes. The main drive motor is then turned off.

3.133 Typical Performance

Typical operating guidelines as well as thickened sludge concentrations and sludge solids removals for various types are presented in Table 3.6.

TABLE 3.6 OPERATIONAL AND PERFORMANCE GUIDELINES FOR CENTRIFUGAL THICKENERS TREATING WASTE ACTIVATED SLUDGE

Centrifuge Type	Capacity, GPM*	Feed Solids, %	Thickened Sludge, %	Solids Recovery, %
Basket	33 - 70	0.7	9 - 10	70 - 90
Scroll	75 - 100	0.4 - 0.7	5 - 7	80 - 90
Disc	30 - 150	0.7 - 1.0	5 - 5.5	90 +

* GPM × 0.063 = *L*/s

The variations in solids loading are due to the many different sizes of centrifuges available from various manufacturers. The performance data reflect no chemical conditioning prior to centrifugation. The addition of polymers normally improves the recovery of suspended solids much more than the recovery of cake solids. For example, look at the solids recovery and cake solids vs polymer dosage curves for both a basket and scroll centrifuge shown in Figures 3.8, 3.9, 3.10, and 3.11. For the basket centrifuge, it can be seen that with no polymer addition, the thickened sludge solids were 4.5 percent and the suspended solids recovery was 75 percent. At a polymer dosage of approximately 5 lbs/ton (2.5 gm/kg), the thickened sludge solids were increased to 6 percent and the solids recovery leveled off at 95 percent. For the scroll centrifuge, the thickened sludge solids remained fairly constant at 7 percent regardless of the polymer dosage. However, with no polymer addition, the solids recovery was at 25 percent and could not reach 90 percent until the polymer dosage exceeded 11 lbs/ton (5.5 gm/kg). In all, the operator must realize that when using polymers, a great deal of experimentation and "tinkering" with both the dosage and point of application must be done to obtain the best results and minimize chemical costs. A more detailed discussion of the basics of chemical conditioning will be presented in Section 3.31.

The determination of centrifuge performance is based on laboratory solids analysis and the following calculations.

EXAMPLE 18

Given: A 22-inch diameter by 60-inch long scroll centrifuge is used to thicken 80 GPM of waste activated sludge (WAS). The WAS has an initial sludge solids concentration of 0.80 percent (8,000 mg/*L*). The centrifuge effluent (centrate) has a sludge solids concentration of 0.20 percent (2,000 mg/*L*).

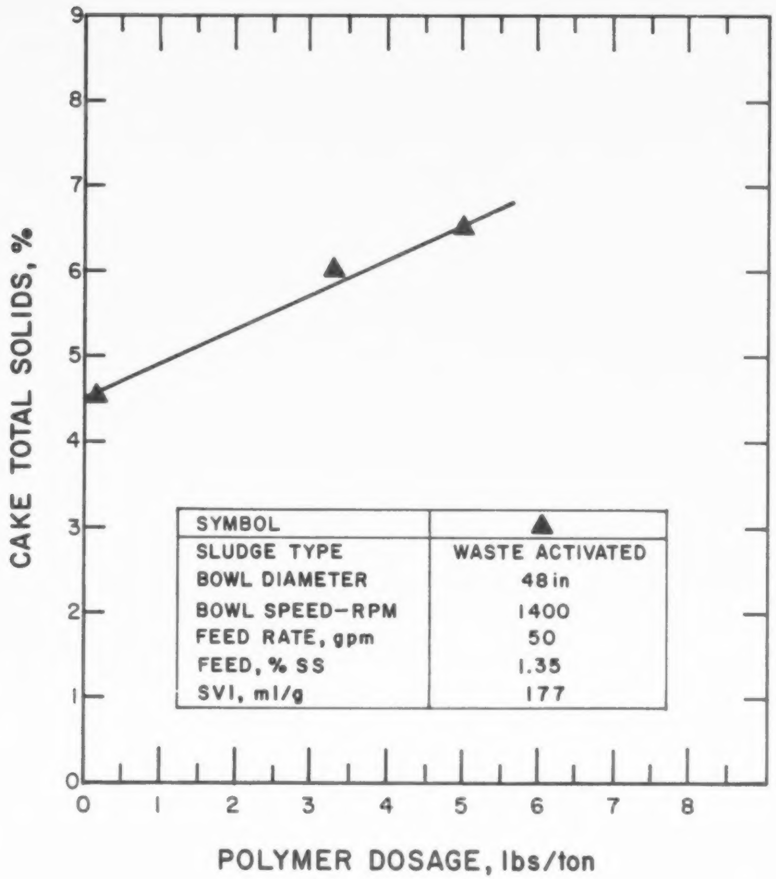

Fig. 3.8 Cake solids from basket centrifuge thickening

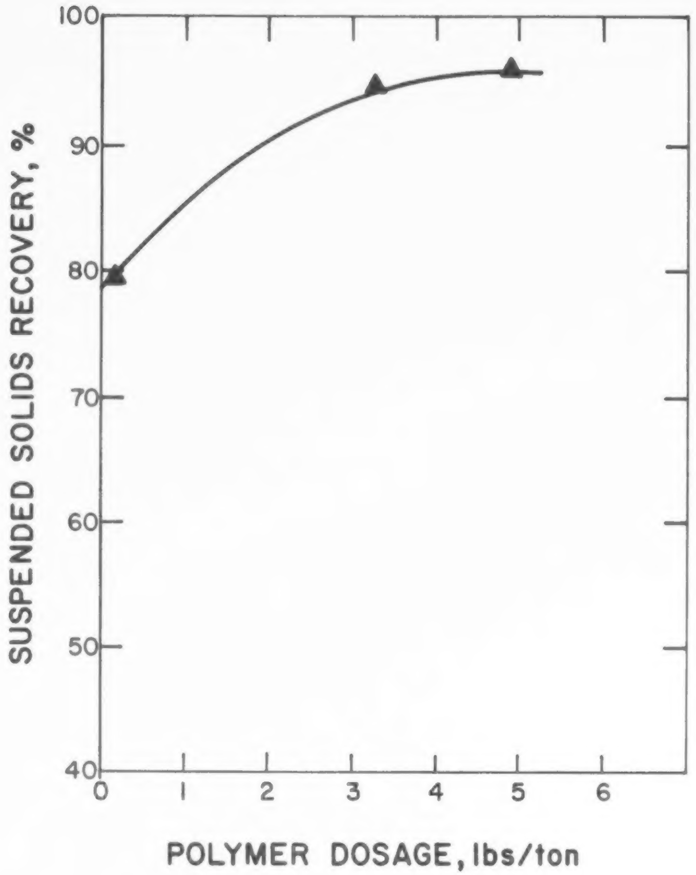

Fig. 3.9 Suspended solids recovery from basket centrifuge thickening

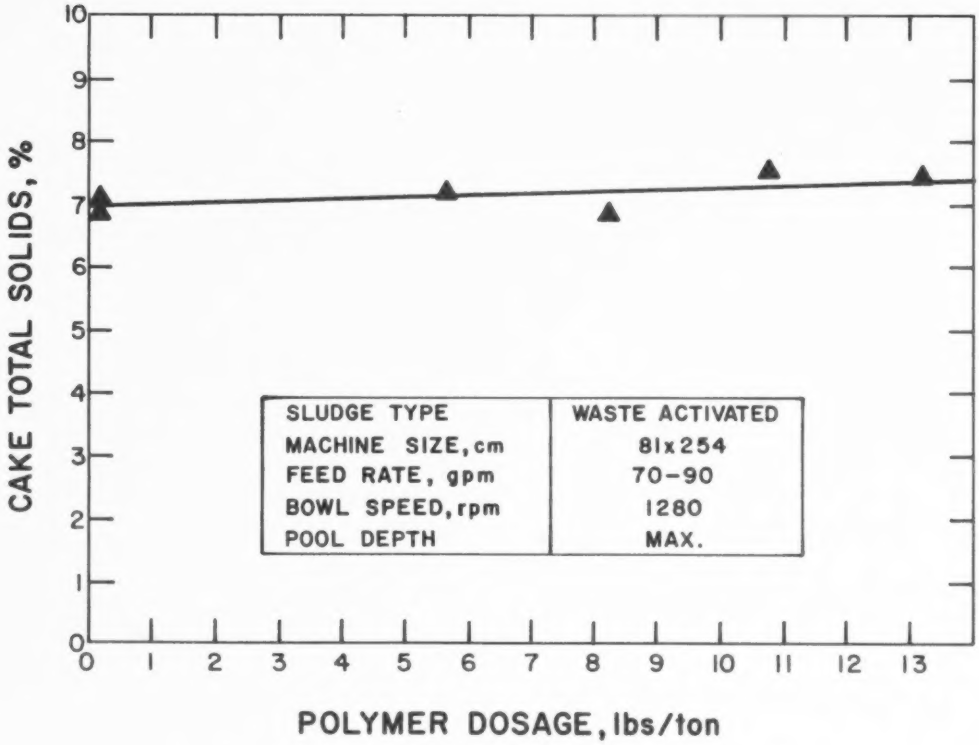

Fig. 3.10 Cake solids from scroll centrifuge thickening

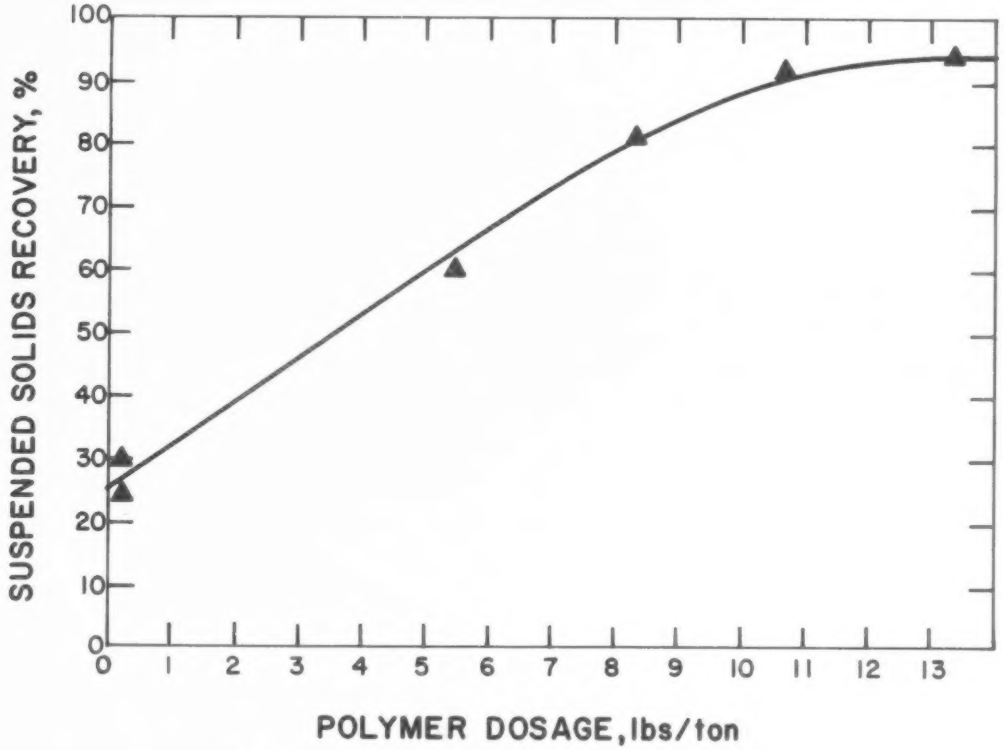

Fig. 3.11 Suspended solids recovery from scroll centrifuge thickening

Find: The sludge solids removal efficiency.

Solution:

Known	Unknown
22-inch diameter by 60-inch long scroll centrifuge	Sludge Solids Removal Efficiency, %
Flow, GPM = 80 GPM	
Infl SS, % = 0.80% , mg/*L* = 8,000 mg/*L*	
Effl SS, % = 0.20% , mg/*L* = 2,000 mg/*L*	

Determine the sludge solids removal efficiency as a percent.

$$\text{Efficiency, \%} = \frac{(\text{Infl SS, \%} - \text{Effl SS, \%}) \times 100\%}{\text{Infl SS, \%}}$$

$$= \frac{(0.80\% - 0.20\%) \times 100\%}{0.80\%}$$

$$= \frac{0.60 \times 100\%}{0.8}$$

$$= 75\%$$

The determination of thickened sludge concentrations (% TS) for scroll and disc centrifuges is based on collecting thickened sludge samples and analyzing for total solids content (% TS) according to procedures outlined in Chapter 16, Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS*. The determination of thickened sludge concentrations of basket centrifuges is more complicated because samples of the skimmed portions and the knifed portion of the retained solids have to be collected, analyzed, and the composite (average solids) have to be calculated based on the relative quantity of skimmed and knifed solids.

EXAMPLE 19

Given: A 48-inch diameter basket centrifuge with a total sludge storage volume of 16 cu ft (120 gal) is used to thicken WAS at an initial suspended solids concentration of 0.80% (8,000 mg/*L*). Approximately 13 cu ft of solids in the basket bowl were skimmed out and the average total solids concentration of the skimmed portion was determined to be 4.0 percent thickened sludge (TS). The remaining 3 cu ft was removed by inserting the knife (plow) and the average concentration of these solids was 7.5 percent total solids.

Find: The average (composite) total solids concentration of the thickened sludge removed from the basket.

Solution:

Known	Unknown
48-inch diameter basket centrifuge	Average Total Thickened Sludge Solids Removed, %
Storage Volume, cu ft = 16 cu ft , gal = 120 gal	
Infl Sl Sol, % = 0.80% , mg/*L* = 8,000 mg/*L*	
Skimmed Volume, cu ft = 13 cu ft	
Skimmed Sl, % = 4.0%	
Knife Volume, cu ft = 3 cu ft	
Knife Solids, % = 7.5%	

Calculate the average thickened sludge solids as a percent.

$$\text{Thickened Sludge, \%} = \frac{\text{Sk Vol, cu ft} \times \text{Sk Sl, \%} + \text{Kn Vol, cu ft} \times \text{Kn Sol, \%}}{\text{Sk Vol, cu ft} + \text{Kn Vol, cu ft}}$$

$$= \frac{13 \text{ cu ft} \times 4.0\% + 3 \text{ cu ft} \times 7.5\%}{13 \text{ cu ft} + 3 \text{ cu ft}}$$

$$= \frac{52 + 22.5}{16}$$

$$= 4.66\%$$

You must realize that this mathematical calculation assumes perfect mixing of the skimmed and knifed solids. In actual practice, perfect mixing is very difficult to achieve.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 250 and 251.

3.13A List the three centrifuge types. Which ones are continuous and which operate in a batch (intermittent feed) mode?

3.13B List the factors that affect centrifugal thickening.

3.13C Why are centrifuges not commonly used to thicken primary sludges?

3.13D Determine the solids and hydraulic loading for a 20-inch by 62-inch scroll centrifuge. The feed rate is 30 gpm and the influent solids concentration is 1.1 percent (11,000 mg/*L*) suspended solids.

3.13E Determine the hydraulic and solids loading for a 48-inch diameter basket centrifuge. The feed rate is 30 gpm, the feed time is 25 minutes and 3 minutes are required to receive the solids and restart the feed. The influent solids concentration is 1.1 percent.

3.13F How does differential scroll speed affect performance of scroll centrifuges?

3.13G A 20-inch disc centrifuge receives 25 gpm of waste activated sludge with a suspended solids concentration of 0.65 percent. The effluent (centrate) contains 0.03 percent SS (300 mg/*L*) and the thickened sludge concentration is 4.9 percent. Determine the percent efficiency and the concentration factor (cf).

3.134 Troubleshooting

Since the operating characteristics of the three centrifuges are quite different, the operating problems and corrective measures also are different. Each of the centrifuges will be discussed for troubleshooting and it should be remembered that *CLOSE VISUAL MONITORING IS THE OPERATOR'S BEST INDICATION OF OPERATIONAL PROBLEMS.*

3.1340 Basket Centrifuge. The operator should be concerned with the concentration of the thickened excess biological sludges. The entire volume of stored sludge can usually be skimmed out without having to use the deceleration and knife insertion sequences when chemical conditioners are not used. If you noticed that the initial skimmings (stored solids farthest from basket wall) contain large quantities of relatively clear water, check the feed time and/or the influent sludge flow. Start feed times and/or low flows will result in only partial filling of the storage volume. If the storage volume is not completely filled with solids prior to discharge, the sludge will be thinner than desired because of dilution with the water discharged. The operator should monitor the centrate quality with time for one complete run, then adjust (increase) the feed time and/or flow rate so that the centrate quality "breaks" when the feed sequence is finished. Conversely, if the thickened sludge concentrations appear to be in a desirable range but the overall centrate quality is poor, the operator should monitor the effluent for one complete run and adjust (decrease) the feed time and/or sludge flow rate. If the feed time and/or sludge flow exceeds the time required to fill the storage volume, the majority of the solids entering the unit beyond the "break" point will exit with the centrate.

If *POLYMERS*[22] are added for conditioning, the net effect will be an increase in feed time, suspended solids recovery and thickened sludge concentrations. If the conditions described above are evident, the operator should check the polymer addition system in addition to procedures mentioned. The use of polymers may also pose an additional problem because the sludge will thicken to a higher degree and the skimmer may not be able to travel all the way to the basket wall. The skimmer will usually proceed towards the wall until it encounters sludge in excess of approximately 6 percent thickened sludge (TS). At this concentration, thickened biological sludges are usually not fluid enough to flow through the skimmer and flow through downstream piping. To remove the remaining stored solids, the deceleration and knife insertion sequence must be used. The problems that may arise could be plugging of the skimmer if it proceeds too far into the thickened sludge, or wet and sloppy discharged solids upon deceleration and knife insertion if the skimmer does not proceed far enough into the sludge. The distance that the skimmer travels is adjustable by set screws on the skimming mechanism. This distance of travel should be set by monitoring a few runs and adjusting as required to obtain a firm and conveyable knifed sludge.

Another problem which may develop with the use of baskets is vibration failures due to plugging of the feed parts and/or uneven solids distribution. This problem usually develops only when dewatering primary sludges and will be discussed in Section 3.4.

3.1341 Scroll Centrifuge. The operational controls for scroll centrifuges on a day-to-day basis usually include relative scroll speed, pool depth, sludge flow, and chemical conditioning when used. Unless the centrifuge is equipped with a hydraulic backdrive, the bowl speed cannot be changed without changing the belt sheaves. In addition, once the optimum bowl speed has been determined and set, there is usually no point in changing it for a given sludge. The same can be said regarding the pool depth because maximum pool depths are commonly used when thickening sludges. This is because in thickening processes it is usually desirable to recover as much of the influent sludge solids as possible.

The performance breakdowns that are commonly encountered are deteriorations in centrate quality and decreases in discharge or cake total solids concentrations. For any given centrifuge, there are upper limits for hydraulic and solids loadings. If these limits are exceeded, both the centrate and cake solids will fall below the desired range. If the centrifuge is operated within its loading limits, the most common problem is a decrease in centrate quality and/or cake dryness. When this problem is evident by visual observation, the operator should adjust the relative scroll speed, monitor the centrate and cake, and readjust the relative scroll speed until the desired results are achieved. If the centrate quality is poor but the cake is within a desired range, increasing the relative scroll speed should result in a cleaner centrate. As the scroll speed is increased, the centrifuged solids are conveyed out at a faster rate and the solids are not given the opportunity to entirely fill the bowl and flow over the effluent weir. To achieve good solids recovery, polymers are usually required when thickening biological solids via scroll centrifugation unless the centrifuge is operated well below its loading capacities. Thickened biological solids are plastic in nature and tend to slip within the bowl as the screw or scroll conveyor tries to move them out. In order to successfully move these solids out of the centrifuge and produce a desirable centrate, polymers are often required. The operator should, therefore, check the polymer conditioning equipment in conjunction with relative scroll speed to optimize centrate quality and thickened sludge concentrations.

3.1342 Disc-Nozzle Centrifuge. Disc-nozzle centrifuges are higher speed units and usually develop centrifugal forces in excess of 3,000 "g's." Because of these high "g" forces, suspended solids recoveries are almost always in excess of 90 percent. Centrate quality usually poses no operational concerns unless the thickened sludge is not adequately removed. The solids will eventually build up and contaminate the centrate. If this happens, the size and/or number of the discharge nozzles should be increased to facilitate sludge discharge. On a day-to-day basis, the nozzles do not have to be changed and the operator should check the hydraulic flow rate if the centrate contains a high amount of suspended solids. Operating at loadings in excess of the recommended range will almost always result in less than optimum performance.

One of the major mechanical problems associated with disc-nozzle centrifugation is plugging of the nozzles because of the relatively small openings (0.07 to 0.08 inch or 1.75 to 2.00 mm). When this occurs, pre-screening of the sludge has to be incorporated into the process sequence. Unless the sludge is adequately screened, the nozzles will continuously plug and interrupt operation of the unit. Plugging will be evident by excessive machine vibrations due to an uneven distribution of solids along the bowl wall. All centrifuges are equipped with vibration switches for automatic shutoff in the event of excessive vibration. If a nozzle becomes plugged, the operator should disassemble the bowl assembly and remove and clean the nozzles prior to restarting the centrifuge.

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[22] *Polymer (POLY-mer). A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."*

Table 3.7 lists operational problems that may develop and corrective measures the operator may take.

TABLE 3.7 TROUBLESHOOTING CENTRIFUGAL THICKENERS

Operational Problem	Possible Causes	Check or Monitor	Possible Solutions
Basket			
1. Centrate quality good but discharge solids dilute	1.a. Feed time too short b. Flow rate too low	1.a. Time for centrate to break b. Sludge flow rate	1.a. Increase feed time b. Increase flow rate
2. Centrate quality poor during the end of the run, but discharge solids o.k.	2.a. Feed time too long b. Flow rate too high c. Incorrect chemical dose	2.a. Time for centrate to break b. Sludge flow rate c. Chemical system	2.a. Lower feed time b. Lower flow rate c. Increase chemical dosage
3. Centrate quality poor and discharge solids dilute	3.a. High loadings b. Insufficient chemicals	3.a. Flow rate and break time b. Chemical system	3.a. Lower flow rate b. Increase chemical dosage
4. Vibrations	4.a. Mechanical malfunctions such as bearings, drive unit, or base support b. Plugged feed port	4.a. Inspect all mechanical equipment	4.a. Mechanical repairs b. Unplug as required
Scroll			
1. Centrate quality good but discharge solids dilute	1.a. Scroll speed too high b. Pool depth too high	1.a. Scroll rpm b. Pool depth	1.a. Decrease scroll speed b. Lower pool depth
2. Centrate poor but discharge solids o.k.	2.a. Scroll speed too slow b. Hydraulic load too high c. Pool depth too low d. Incorrect chemical dose	2.a. Scroll rpm b. Flow rate c. Pool setting d. Chemical system	2.a. Increase scroll speed b. Decrease flow c. Increase pool d. Increase chemical dosage
3. Centrate poor and discharge solids dilute	3.a. Bowl speed too low b. Loading too high c. Chemical inefficiencies d. Scroll speed and pool depth not optimum	3.a. Bowl rpm b. Flow rate c. Chemical system d. Scroll rpm and pool depth	3.a. Increase bowl speed b. Decrease flow rate c. Increase chemical dosage d. Vary scroll speed and pool depth
Disc-Nozzle			
1. Centrate good but discharge solids dilute	1.a. Size and number of nozzles too large	1.a. Nozzles	1.a. Decrease number and/or size of nozzles
2. Centrate poor but discharge solids o.k.	2.a. Size and number of nozzles too large b. Hydraulic load too high	2.a. Nozzles b. Flow rate	2.a. Increase number and/or nozzle size b. Decrease flow rate
3. Vibrations	3.a. Mechanical malfunctions such as bearings, drive unit, or base support b. Plugged nozzle	3.a. Inspect all mechanical equipment b. Nozzle	3.a. Mechanical repairs b. Unplug as required

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 251.

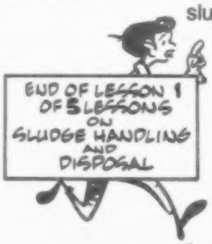
3.13H A scroll centrifuge is used to thicken waste activated sludge. On a routine check, the operator notices a poor centrate quality. The discharge solids are good. What should the operator check and what action should be taken?

3.13I How can the concentration of thickened sludge be increased from a disc centrifuge and how can the changes affect centrate quality?

3.14 Thickening Summary

The successful operation of any thickening device is dependent on the operator's knowledge of the operating guidelines, the consistency of the influent sludge, maintaining loading rates within the recommended and design values, and when used, effective polymer addition.

For optimum operation of subsequent sludge processes (stabilization, dewatering), the thickener should be operated so as to produce as thick a sludge as possible with maximum sludge solids recovery.



DISCUSSION AND REVIEW QUESTIONS

Chapter 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 1 of 5 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. Why is the handling and disposal of sludge such a complicated problem?
2. List the major types of alternatives available for processing sludges.
3. What are the advantages normally associated with sludge thickening?
4. How does temperature affect the operation of gravity thickeners?
5. The performance of dissolved air flotation thickeners depends upon what factors?
6. What is the most important operational concern when operating a dissolved air flotation thickener?
7. What is the best way for an operator to detect operational problems in a centrifuge?

CHAPTER 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 2 of 5 Lessons)

3.2 STABILIZATION[23]

3.20 Purpose of Sludge Stabilization

Prior to the disposal of wastewater treatment plant sludges, federal, state and local regulatory agencies require that they be stabilized. Stabilization converts the volatile (organic) or odor-causing portion of the sludge solids to nonodorous end products, prevents the breeding of insects upon disposal and reduces the pathogenic (disease carrying) bacteria content.

Unit processes commonly used for stabilization of wastewater sludges include: (1) anaerobic digestion, (2) aerobic digestion, and (3) chemical treatment.

Anaerobic digestion has been explained in great detail in Chapter 12, "Sludge Digestion and Solids Handling," Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS*, and only a brief review of the process will follow. The remainder of this section will discuss aerobic digestion and chemical treatment.

3.21 Anaerobic Digestion

The most widely used method of sludge stabilization is anaerobic digestion, in which decomposition of organic matter is performed by microorganisms in the absence of oxygen. Anaerobic digestion is a complex biochemical process in which several groups of anaerobic and facultative (survive with or without oxygen) organisms break down organic matter. This process can be considered a two-phase process; in the first phase, facultative acid-forming organisms convert complex organic matter to volatile (organic) acids. In the second phase, anaerobic methane-forming organisms convert the acids to odorless end products of methane gas and carbon dioxide.

The performance of anaerobic digesters in converting volatile (organic) matter to methane and carbon dioxide depends on (1) sludge type, (2) digestion time, (3) digestion temperature, and (4) mixing. In general, as the concentration of sludge solids fed to anaerobic digesters increases, the performance or efficiency in converting volatile sludge solids also increases due to lower sludge volumes and longer digestion times. In addition, the methane-forming bacteria are highly sensitive to temperature changes and anaerobic digesters are usually heated to maintain temperatures of 94 to 97°F (34 to 36°C). If the temperature falls below this range and/or if the digestion time falls below 15 days, the digester may become upset and require close monitoring and attention. Refer to Chapter 12, "Sludge Digestion and Solids Handling," for a detailed discussion of operating procedures and corrective measures required during upset conditions.

3.22 Aerobic Digestion

Aerobic digestion involves the conversion of organic sludge solids to odorless end products of carbon dioxide and water by aerobic microorganisms. This process essentially evolved from the extended-aeration version of the activated sludge process, and may be used for either primary sludge, secondary sludge, or mixtures of the two types of sludges.

Sludge to be stabilized is delivered to the aerobic digester on a continuous or an intermittent basis. A few aerobic digesters are operated on a batch basis. Figure 3.12 shows a typical aerobic digestion process in a schematic fashion. When operated in a continuous mode, thickened sludge is fed continuously to the digester inlet. The digester is equipped with blowers and air diffusion equipment to supply oxygen to the system and to provide for mixing of the digester contents. Digested sludge continuously exits through an effluent line and is either pumped directly to dewatering facilities or may flow to a gravity thickener prior to dewatering. The use of thickening equipment following digestion is to concentrate the sludge and reduce the hydraulic loadings on subsequent dewatering equipment. The overflow (effluent) from the thickener is usually pumped back to the plant headworks for more treatment. The underflow (solids) from the thickener is pumped to the dewatering facilities. If thickeners are not used, the digested sludge is pumped directly to the dewatering facilities.

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[23] *Stabilization. Conversion to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.*

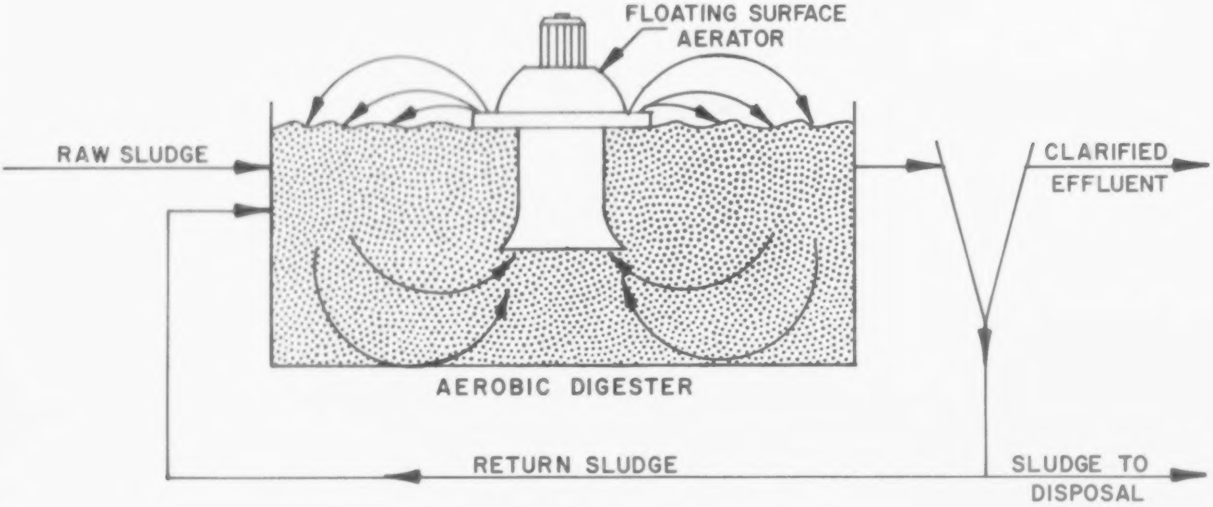

Fig. 3.12 Aerobic sludge digestion process

In the intermittent or batch mode of operation, the digester receives thickened sludge for a portion of the day. After the digester is fed, the blowers and air diffusion equipment remain in operation until approximately 2 to 3 hours before the next feeding. At 2 to 3 hours before the next feeding, the blowers are turned off and the digester contents are allowed to settle for approximately 1½ to 2½ hours. A portion of the settled solids are then withdrawn and pumped to sludge dewatering facilities. A portion of the supernatant (top) liquor is also withdrawn for either recycle to the plant influent or further treatment with the plant secondary effluent. The blowers are then turned on and thickened sludge is again pumped to the aerobic digester to replace the volume of sludge withdrawn. From an operations standpoint, the continuous mode of feeding is preferred because it tends to minimize operator attention and to reduce associated operational costs.

3.220 Factors Affecting Aerobic Digestion

The operation and performance of aerobic digesters are affected by many variables. These include: (1) sludge type, (2) digestion time, (3) digestion temperatures, (4) volatile solids loading, (5) quantity of air supplied, and (6) dissolved oxygen (DO) concentrations within the digester.

The sludge type deals with the influent characteristics of the waste stream to be stabilized. The operator has little, if any, control over the chemical and biological make-up of the influent sludge. As stated earlier, aerobic digestion may be used for either primary sludge, secondary sludge, or mixtures of the two. The process has found its widest application with secondary sludges. Secondary sludges are composed primarily of biological cells that are produced in the activated sludge and/or trickling filter processes as a by-product of degrading organic matter. In simplified terms, by the time secondary sludges leave the biological treatment process, settle in final clarifiers, concentrate in sludge thickening units, and are delivered to aerobic digesters, the quantity of available food (organic matter) is substantially reduced. In the absence of an external food source, these microorganisms enter the *ENDOGENOUS*[24] or death phase of their life cycle. When no food is available (endogenous phase), the biomass begins to self-metabolize (self-destruct), which results in a conversion of the biomass to end products of carbon dioxide and water and a net decrease in the sludge mass.

When primary sludge is introduced to an aerobic digester, food becomes available to the microorganisms. In the presence of an external food source (the primary sludge), the biomass will convert the food to end products of carbon dioxide and water and will function in the growth phase of their life cycle until the food supply is exhausted. During this growth phase, the biomass will reproduce resulting in a net increase in the sludge mass. Aerobic digestion times are long enough to allow the food to be depleted and the biomass to eventually enter the endogenous or death phase. The main drawback to aerobically digesting primary sludge is that more air has to be supplied to maintain a desirable DO level because the bacteria are more active when food is available.

Digestion time, temperature, volatile solids loading and air supply are considered operational controls and are discussed below.

3.221 Operating Guildelines

3.2210 Digestion Time. In general, as the digestion time is increased, the efficiency or effectiveness of aerobic digesters in achieving the goals of stabilization is also increased. The physical size of aerobic digesters is determined by engineers and the operator has no control over the digester volume after it is constructed. The operator does have control over the digestion time by controlling the degree of sludge thickening prior to digestion. The digestion time is directly proportional to the thickened sludge flow according to the following equation:

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[24] *Endogenous (en-DODGE-en-us). A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.*

$$\text{DIGESTION TIME, days} = \frac{\text{DIGESTER VOLUME, gal}}{\text{SLUDGE FLOW, gal/day}}$$

As the flow to the digester increases, the time of digestion decreases; as the flow decreases, the digestion time increases. The following example illustrates the effect of sludge concentration and the resulting sludge volume on digestion time.

EXAMPLE 20

Given: A 40-foot diameter by 10-foot side-wall-depth (SWD) aerobic digester receives 10,000 GPD of thickened secondary sludge. The thickened sludge concentration is 2.5 percent (25,000 mg/*L*) sludge solids (total solids).

Find: 1. The time of digestion.
2. What effect thickening the sludge to 3.5 percent sludge solids will have on digester performance.

Solution:

Known		**Unknown**
Aerobic Digester		Digestion Time, days
Diameter, ft	= 40 ft	Effect of Increasing Sludge Solids to 3.5%
Depth (SWD), ft	= 10 ft	
Flow, GPD	= 10,000 GPD	
Thickened Sludge, %	= 2.5% Sludge Solids	
mg/*L*	= 25,000 mg/*L*	

1. Calculate the digestion time in days.
   a. Calculate the digester volume.

$$\begin{aligned}\text{Volume, gal} &= \frac{\pi}{4} \times (\text{Diameter, ft})^2 \times \text{SWD, ft} \times 7.48\ \frac{\text{gal}}{\text{cu ft}}\\ &= \frac{\pi}{4} \times (40\text{ ft})^2 \times 10\text{ ft} \times 7.48\ \frac{\text{gal}}{\text{cu ft}}\\ &= 94{,}000\text{ gal (approximate)}\end{aligned}$$

   b. Determine the digestion time in days.

$$\begin{aligned}\text{Digestion Time, days} &= \frac{\text{Digester Volume, gallons}}{\text{Flow, GPD}}\\ &= \frac{94{,}000\text{ gal}}{10{,}000\text{ gal/day}}\\ &= 9.4\text{ days}\end{aligned}$$

NOTE: The digestion time in days based on the solids in the digester is more important than the hydraulic digestion time.

$$\text{Digestion Time, days (solids)} = \frac{\text{Digester Solids, lbs}}{\text{Sludge Wasted, lbs/day}}$$

2. Determine the effect of increasing the sludge solids from 2.5 percent to 3.5 percent sludge solids. The total sludge volume pumped to the aerobic digester will be decreased and the digestion time will be increased. Calculate the new digestion time in days.
   a. Determine the new flow to the aerobic digester in gallons per day.

$$\begin{aligned}\text{Flow, GPD} &= \frac{\text{Flow at 2.5\% SS, GPD} \times \text{SS, \%}}{\text{SS, \%}}\\ &= \frac{10{,}000\text{ GPD} \times 2.5\%}{3.5\%}\\ &= 7{,}143\text{ GPD}\end{aligned}$$

   b. Calculate the new digestion time.

$$\begin{aligned}\text{Digestion Time, days} &= \frac{\text{Digester Volume, gallons}}{\text{Flow, GPD}}\\ &= \frac{94{,}000\text{ gal}}{7{,}143\text{ gal/day}}\\ &= 13.2\text{ days}\end{aligned}$$

The overall impact of thickening the sludge to 3.5 percent sludge solids is an increase in digestion time and a potential increase in digester efficiency.

The above example illustrates the need to *THICKEN SLUDGE AS MUCH AS POSSIBLE PRIOR TO STABILIZATION TO OBTAIN MAXIMUM DIGESTION TIMES.*

3.2211 Digestion Temperature. Aerobic digestion, like the activated sludge process, depends on groups of microorganisms performing specific functions. These microorganisms, as every living creature, require favorable environments to function properly. An important environmental condition is the maintenance of desirable temperatures. As the temperature of the system decreases, the rate of biological activity also decreases. In the case of aerobic digestion, a decrease in biological activity will result in a decreased rate of destruction of the biomass and the potential for unstabilized sludge exiting the digester. Desirable aerobic digestion temperatures are approximately 65 to 80°F (18 to 27°C) and in colder climates, provisions may have to be made to heat the digester to maintain temperatures in the above range. In addition, if aerobic digesters are fabricated with steel and erected above ground, sufficient insulation should be provided to prevent excess heat loss and reduce heating costs. Actual temperatures in aerobic digesters depend on the temperature and volume of sludge fed to the digester and also the temperature of the air coming from the blowers to the digester.

3.2212 Volatile Solids Loading. Volatile sludge solids loading is an estimate of the quantity of organic matter applied to the digester. Procedures of calculating sludge solids concentration are outlined in Chapter 16, "Laboratory Procedures and Chemistry." The optimum volatile solids loading for aerobic digestion (and anaerobic digestion) depends on the treatment plant and is generally determined by pilot and/or full scale experimentation. In general, volatile sludge solids (VSS) loadings for effective aerobic stabilization vary from 0.07 lb VSS/day/cu ft to 0.20 lb VSS/day/cu ft, depending on the temperature and type of sludge.

The operator should be familiar with the calculations required to determine volatile suspended solids loading rates. The following example outlines these calculations and it should be noted that the determination of volatile sludge solids loading is identical for aerobic and anaerobic stabilization processes.

EXAMPLE 21

Given: A 40-foot diameter by 10-foot SWD aerobic digester receives 7,140 GPD of secondary sludge. The thickened secondary sludge is at a concentration of 3.5 percent sludge solids and is 75 percent volatile matter.

Find: The volatile sludge solids loading (lb VSS/day/cu ft).

Solution:

Known		Unknown
Aerobic Digester		Volatile Sludge Solids Loading, lb VSS/day/cu ft
Diameter, ft	= 40 ft	
Depth (SWD), ft	= 10 ft	
Flow, GPD	= 7,140 GPD	
Sludge Solids, %	= 3.5%	
Volatile Matter, %	= 75%	

Calculate the volatile sludge solids (VSS) loading in pounds of VSS per day per cubic foot of aerobic digester.

a. Determine the digester volume in cubic feet.

$$\begin{aligned}\text{Volume, cu ft} &= \frac{\pi}{4} \times (\text{Diameter, ft})^2 \times \text{Depth, ft}\\ &= \frac{\pi}{4} \times (40\text{ ft})^2 \times 10\text{ ft}\\ &= 12{,}566\text{ cu ft}\end{aligned}$$

b. Calculate the volatile sludge solids (VSS) loading in pounds of VSS per day per cubic foot.

$$\begin{aligned}\text{VSS Loading, lbs VSS/day/cu ft} &= \frac{\text{VSS Added, lbs/day}}{\text{Digester Volume, cu ft}}\\ &= \frac{\text{Flow, GPD} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%} \times \frac{\text{VM, \%}}{100\%}}{\text{Digester Volume, cu ft}}\\ &= \frac{7{,}140\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{3.5\%}{100\%} \times \frac{75\%}{100\%}}{12{,}566\text{ cu ft}}\\ &= \frac{1{,}563\text{ lbs VSS/day}}{12{,}566\text{ cu ft}}\\ &= 0.12\text{ lbs VSS/day/cu ft}\end{aligned}$$

The VSS loading is affected by the concentration and volume of sludge introduced into the digester. In general, the volatile portion of a sludge from a particular plant will not vary from day to day. If the digestion capacity is fixed, the daily sludge flow in combination with the degree of thickening will determine the VSS loading.

3.2213 Air Requirements and Dissolved Oxygen. Oxygen is supplied to the sludge by using air diffusers or mechanical aerators. Air requirements are usually expressed as cfm air/1000 cu ft of aerobic digester capacity for diffuser systems, and as horsepower per 1,000 cubic feet for mechanical aerators. Air requirements also are expressed as 1.5 to 2 pounds of oxygen per pound of volatile sludge solids destroyed. The air requirements are governed by a desire to keep the digester solids in suspension (well mixed) and to maintain a dissolved oxygen (DO) concentration of 1 to 2 mg/*L* within the digester.

Depending on the sludge type, temperature, and concentration and the activity of biomass within the digester, the quantity of air required to maintain a residual DO of 1 to 2 mg/*L* will vary. Obviously, as the concentration and/or activity increases, more air is required to satisfy the oxygen requirements of the biomass. The residual DO is a measure of the quantity of oxygen supplied beyond that used by the biomass. For example, if the biomass requires 3.0 mg/*L* of oxygen and 5.0 mg/*L* are supplied via the blowers or mechanical aerators, then 2.0 mg/*L* of oxygen are left over. The quantity left over is called the residual DO. The residual DO within the digester should always be greater than 1.0 mg/*L*. If the digester DO falls below 1.0 mg/*L*, *FILAMENTOUS ORGANISMS*[25] may grow. Filamentous organisms are undesirable because they can lead to sludge bulking and/or foaming which will negatively affect digester operation.

Typical air rates required to maintain a residual DO of 1.0 to 2.0 mg/*L*, are discussed in Section 3.223, "Typical Performance." You should realize that values in any book are estimates and that the exact air supply requirements are usually determined in the plant by experimentation. The following example illustrates the determination of air rates for aerobic digesters.

EXAMPLE 22

Given: A pilot-scale digestion study showed that 0.040 CFM of air was required per cu ft of digestion capacity to satisfy the biomass oxygen requirements. Based on these pilot studies, a full-scale digester with dimensions of 100 ft long by 25 ft wide by 10 ft SWD has been constructed.

Find: The quantity of air (CFM) to be delivered to the full-scale digester.

Solution:

Known		Unknown
Aerobic Digester		Air Rate, CFM
Air Required, CFM/cu ft	$= \frac{0.040\text{ CFM air}}{\text{cu ft digester}}$	
Length, ft	= 100 ft	
Width, ft	= 25 ft	
SWD, ft	= 10 ft	

Determine the rate of air that must be delivered to the aerobic digester in cubic feet of air per minute (CFM).

a. Calculate the digester volume in cubic feet.

$$\begin{aligned}\text{Digester Volume, cu ft} &= \text{Length, ft} \times \text{Width, ft} \times \text{SWD, ft}\\ &= 100\text{ ft} \times 25\text{ ft} \times 10\text{ ft}\\ &= 25{,}000\text{ cu ft}\end{aligned}$$

b. Determine the rate of air that must be supplied in CFM.

$$\begin{aligned}\text{Air Rate, CFM} &= \frac{\text{Air Required, CFM air}}{\text{cu ft Digester}} \times \text{Dig. Vol, cu ft}\\ &= \frac{0.040\text{ CFM air}}{\text{cu ft digester}} \times 25{,}000\text{ cu ft}\\ &= 1{,}000\text{ CFM air}\end{aligned}$$

3.222 Normal Operating Procedures

The sludge feed to aerobic digesters should be as continuous and consistent as possible. This is best achieved by proper operation of the sludge thickening facilities and by pumping the thickest possible sludge. Aerobic digesters should be routinely checked at least once per shift and composite samples of the influent and effluent should be collected daily for laboratory analysis. Daily laboratory analysis on the influent and effluent streams should include suspended solids, percent volatile matter, and pH measurements. Alkalinity, total and soluble COD, ammonia-nitrogen, nitrite and nitrate should be determined on the influent and effluent weekly. In addition to these laboratory analyses, the residual dissolved oxygen (DO) in the digester should be measured at least once per shift. Digester temperature should be measured daily.

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[25] *Filamentous Organisms (FILL-a-MEN-tuss). Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomyces.*

Digester temperature measurements are straightforward and simply involve the use of a thermometer. The determination of dissolved oxygen (DO) in the digester and oxygen (O_2) uptake rates require the use of a membrane-type electrode commonly called a DO probe. Membrane electrode instruments are commercially available in some variety and it is impossible to formulate detailed operational instructions that would apply to every instrument. Calibration procedures and readout are included in manufacturer's instructions and they should be followed exactly to obtain the guaranteed precision and accuracy.

Residual DO in the digester can simply be measured by lowering the probe into the digester, gently raising and lowering the probe approximately 6 to 12 inches (15 to 30 cm) and recording the readout measurement after the readout has stabilized. Depending on the instrument readout measurement and the temperature of the digester, the DO can be determined in mg/*L* with the aid of charts supplied by the electrode manufacturer. DO measurements should be obtained from at least 3 points within the digester to obtain an average dissolved oxygen concentration. These measurements should be obtained at the influent and effluent ends of the digester and approximately midway along the length of the digester.

Oxygen uptake measurements are an indication of the activity of the aerobic digester biomass. Accurate *OXYGEN (O_2) UPTAKE MEASUREMENTS* are of importance to the operator because they will readily indicate *IF THE PROCESS IS FUNCTIONING PROPERLY OR IF UPSET CONDITIONS EXIST.* Oxygen uptake measurement requires the use of a sealed container into which a DO probe and a mixer can be inserted to measure the oxygen concentration with time. Approximately one liter of digested sludge should be collected in a wide-mouth container, the top sealed and the container vigorously mixed. Vigorous mixing will saturate the sample with oxygen. Following approximately ½ to 1 minute of mixing, the oxygen-saturated sample is placed into the oxygen uptake container, the DO probe inserted and the mixer turned on. The DO concentrations are then recorded with time for 10 to 15 minutes or until zero DO is recorded. The uptake measurement is then calculated according to the following equation:

$$\text{Oxygen Uptake, mg}/L/\text{hr} = \frac{(\text{DO}_1,\ \text{mg}/L - \text{DO}_2,\ \text{mg}/L)}{(\text{Time}_2,\ \text{min} - \text{Time}_1,\ \text{min})} \times \frac{60\ \text{min}}{\text{hr}}$$

The following example illustrates the determination of O_2 uptake:

EXAMPLE 23

Given: An operator measures the dissolved oxygen (DO) concentration with time on an air-saturated sample taken from an aerobic digester. The following measurements were recorded:

Time	D.O. (mg/*L*)
0 Min	7.1
1 Min	6.0
2 Min	5.2
3 Min	4.5
4 Min	3.9
5 Min	3.2

Find: The oxygen uptake in mg/*L*/hr.

Solution:

Known	Unknown
Aerobic Digester	Oxygen Uptake, mg/*L*/hr
DO Measurements with Time for an Air-Saturated Sample	

Calculate the oxygen uptake for the air-saturated sample from an aerobic digester in mg/*L*/hr. Generally the 2-minute DO reading is used in order to allow the DO probe and the sample time to stabilize. The 5-minute DO reading also is used in the calculation.

$$\begin{aligned}\text{Oxygen Uptake, mg}/L/\text{hr} &= \frac{(\text{DO}_1,\ \text{mg}/L - \text{DO}_2,\ \text{mg}/L)}{(\text{Time}_2,\ \text{min} - \text{Time}_1,\ \text{min})} \times \frac{60\ \text{min}}{\text{hr}} \\ &= \frac{(5.2\ \text{mg}/L - 3.2\ \text{mg}/L)}{(5\ \text{min} - 2\ \text{min})} \times \frac{60\ \text{min}}{\text{hr}} \\ &= \frac{2.0\ \text{mg}/L}{3\ \text{min}} \times \frac{60\ \text{min}}{\text{hr}} \\ &= 40\ \text{mg}/L/\text{hr}\end{aligned}$$

If the uptake measurement and residual DO measurements are significantly different than those values usually measured, the operator should be aware that something may be wrong (see Section 3.2240). Change in oxygen uptake rates could indicate the presence of substances capable of inhibiting the activities of the organisms treating the sludge.

Like a well-operated activated sludge system, a well-operated aerobic digester should be relatively free of odors. The surface will contain a small accumulation of foam due to the turbulence created by the diffusers or mechanical aerators and the operator should be aware of changes in the physical appearance of the system. The operator soon comes to think of an aerobic digester as a living organism. The organisms thrive and enjoy good health or become upset and refuse to function properly. By combining careful observation with experience, you may determine what is happening and what adjustments, if any, are required. Section 3.224 deals with troubleshooting.

3.223 Typical Performance

Table 3.8 shows typical operating guidelines for aerobic digestion and includes a summary of performance to be expected.

TABLE 3.8 OPERATIONAL AND PERFORMANCE GUIDELINES FOR AEROBIC DIGESTION

Sludge Type	Digestion Time, days	Air Rate		VSS Load, lb VSS/day/cu ft[c]	VSS Destruction, %
		Diffused Air, CFM/cu ft[a]	Mechanical, HP/1000 cu ft[b]		
Primary	15-20	0.015-0.06	0.05-1.25	.08-.20	25-50
Secondary	10-15	0.015-0.04	0.05-1.25	.08-.20	25-40

[a] CFM/cu ft × 1.0 = Cu M/min/Cu M
[b] HP/1000 cu ft × 26.34 = W/cu m
[c] lb VSS/day/cu ft × 10.02 = kg/day/cu m

The efficiency of aerobic digesters is usually measured by the quantity of suspended and volatile (sludge) solids converted to end products of CO_2 and H_2O.

The following example illustrates how to calculate the efficiency of aerobic digesters.

EXAMPLE 24

Given: An aerobic digester receives 9,000 GPD of secondary sludge at a concentration of 3.6 percent sludge solids (SS) and 74 percent volatile solids (matter). The digester effluent is at a concentration of 2.6 percent sludge solids and 64 percent volatile matter.

Find:
1. Pounds of sludge solids (SS) and pounds of volatile sludge solids (VSS) entering the digester.
2. Pounds of sludge solids and pounds of volatile sludge solids exiting the digester.
3. Efficiency of digester in destroying sludge solids, %.

4. Efficiency of digester in destroying volatile sludge solids, %.

Solution:

Known		Unknown
Aerobic Digester		1. Sludge, Solids, In, lbs/day
Flow, GPD	= 9,000 GPD	Volatile Solids In, lbs/day
Sludge Solids In, %	= 3.6%	2. Sludge Solids Out, lbs/day
Volatile Solids In, %	= 74%	Volatile Solids Out, lbs/day
Sludge Solids Out, %	= 2.6%	3. Sludge Solids Removal Eff, %
Volatile Solids Out, %	= 64%	4. Volatile Solids Removal Eff, %

1. Determine the sludge solids and volatile solids entering the aerobic digester in pounds per day.

$$\begin{aligned}\text{Sludge Solids Entering, lbs/day} &= \text{Flow, GPD} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{SS In, \%}}{100\%}\\ &= 9{,}000\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{3.6\%}{100\%}\\ &= 2{,}702\text{ lbs SS/day}\end{aligned}$$

$$\begin{aligned}\text{Volatile Solids Entering, lbs/day} &= \text{Sludge Solids, }\frac{\text{lbs}}{\text{day}} \times \frac{\text{VSS, \%}}{100\%}\\ &= 2{,}702\,\frac{\text{lbs SS}}{\text{day}} \times \frac{74\%}{100\%}\\ &= 2{,}000\text{ lbs VSS/day}\end{aligned}$$

2. Determine the sludge solids and volatile solids exiting the aerobic digester in pounds per day.

$$\begin{aligned}\text{Sludge Solids Exiting, lbs/day} &= \text{Flow, GPD} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{SS Out, \%}}{100\%}\\ &= 9{,}000\,\frac{\text{gal}}{\text{day}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{2.6\%}{100\%}\\ &= 1{,}952\text{ lbs SS/day}\end{aligned}$$

$$\begin{aligned}\text{Volatile Solids Exiting, lbs/day} &= \text{Sludge Solids, }\frac{\text{lbs}}{\text{day}} \times \frac{\text{VSS, \%}}{100\%}\\ &= 1{,}952\,\frac{\text{lbs SS}}{\text{day}} \times \frac{64\%}{100\%}\\ &= 1{,}249\text{ lbs VSS/day}\end{aligned}$$

3. Calculate the efficiency of the sludge solids destruction as a percent.

$$\begin{aligned}\text{SS Destruction Efficiency, \%} &= \frac{(\text{SS Entering, lbs/day} - \text{SS Exiting, lbs/day}) \times 100\%}{\text{SS Entering, lbs/day}}\\ &= \frac{(2702\text{ lbs SS/day} - 1952\text{ lbs SS/day}) \times 100\%}{2702\text{ lbs SS/day}}\\ &= 27.8\%\end{aligned}$$

4. Calculate the efficiency of the volatile sludge solids destruction as a percent.

$$\begin{aligned}\text{VSS Destruction Efficiency, \%} &= \frac{(\underset{\text{lbs/day}}{\text{VSS Entering,}} - \underset{\text{lbs/day}}{\text{VSS Exiting,}}) \times 100\%}{\text{VSS Entering, lbs/day}}\\ &= \frac{(2{,}000\text{ lbs VSS/day} - 1249\text{ lbs VSS/day}) \times 100\%}{2{,}000\text{ lbs VSS/day}}\\ &= 37.6\%\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 251 and 252.

3.20A What are the goals of stabilization?

3.20B List the unit processes commonly used for stabilization.

3.21A Explain the two-step process of anaerobic digestion.

3.22A Briefly explain the aerobic digestion process.

3.22B Why is continuous feeding of aerobic digesters preferred over batch draw-and-fill systems?

3.22C List the factors affecting aerobic digestion.

3.22D Briefly explain why aerobic digestion is more suitable for treating secondary sludges than treating primary sludges.

3.22E How can an operator control the digestion time?

3.22F A digester with an active volume of 140,000 cubic feet receives 110,000 gpd of primary sludge. What is the digestion time (days)?

3.22G If the sludge from problem 22.22F is thickened from 2.7 percent to 3.5 percent, what will happen to the digestion time?

3.22H How does temperature affect aerobic digester performance?

3.22I An aerobic digester with dimensions of 120 ft in length, 25 feet wide, and 11 feet SWD receives 24,000 gpd of secondary sludge at a concentration of 3.1 percent and 73 percent volatile matter. What is the digestion time (days) and the VSS loading (lbs/day/cu ft)?

3.22J Why should the DO in aerobic digesters be maintained at concentrations greater than 1.0 mg/*L*?

3.22K Explain how the DO level is determined in aerobic digesters.

3.22L Determine the O_2 uptake rate for the following field measurements:

Time (min)	DO (mg/*L*)
0	6.3
1	5.1
2	4.2
3	3.4
4	2.6
5	1.8
6	1.0

3.22M A 1,000,000 gallon aerobic digester receives 91,000 gpd of primary sludge at a concentration of 5.1 percent SS and 76 percent volatile matter. The digester effluent is at a concentration of 3.7 percent SS and 67 percent volatile matter. Determine the digestion time (days), VSS loading (lbs/day/cu ft) and percent VSS destruction.

3.224 Troubleshooting

Aerobic digesters, like all biological systems, are subject to upsets. These upsets may result from equipment malfunctions, changes in the influent characteristics and/or operation out of the range of recommended operating guidelines.

Even before sample analyses are available from the laboratory, the operator may become aware of process inefficiencies by careful observation of the physical appearance of the digested sludge and routine monitoring of the residual dissolved oxygen.

3.2240 Dissolved Oxygen and Oxygen Uptake. After an aerobic digester reaches steady state, that is, the concentration of solids within the digester is fairly constant, the O_2 uptake rate and residual DO should be relatively constant from day to day. If the residual DO increases significantly, the operator should be aware that either the air rate is excessive or the O_2 uptake rate and activity of the biomass has decreased. The O_2 uptake should be checked immediately. If the O_2 uptake is in the range normally encountered, then the biomass is functioning properly and the increase in DO is most likely due to high air rates to the digester. The operator should check the air rate and adjust as required to maintain a DO of 1 to 2 mg/*L*. Excessive air rates are not desired because they may cause high turbulence within the digester which may adversely affect sludge settleability and may lead to foaming problems. If the O_2 uptake rate is significantly lower than normal, the operator should be aware that something may be inhibiting the biomass. The operator should check the temperature and pH of the digester contents. A significant decrease in the temperature or pH will reduce the activity of the biomass. If the temperature is low, the operator should try to determine what could have caused the drop in temperature and how the temperature can be returned to the normal operating range. If the pH is significantly lower than normal (6.8 to 7.3), the operator may have to add caustic or lime for pH adjustment. A decline in the pH may be caused by nitrification in the digester or by changes in the influent sludge characteristics. If the decline is caused by nitrification, the decrease in pH will be gradual over about a week's time. A review of the daily pH measurements will indicate whether the decline was gradual or not. If nitrification is the cause of a decrease in pH, the operator may lower the air rate somewhat and/or decrease the hydraulic detention time somewhat to suppress the growth of nitrifying bacteria. In any case, the pH should not be allowed to drop below 6.0. If the pH is below or close to 6.0, the operator should take immediate action to neutralize the digester contents. The safest and easiest way to determine the quantity of lime ($Ca(OH)_2$) or caustic (NaOH) to be added is to conduct jar tets (see page 171, JAR TEST PROCEDURE) on the digested sludge according to the following example.

EXAMPLE 25

Given: The pH of an aerobic digester has declined to 6.1. The operator wishes to raise the pH to 7.0 with the addition of sodium hydroxide.

Find: How much caustic must be added if the digester volume is 100,000 gallons.

Procedure: The operator should run jar tests on the digested sludge and determine how much must be added to a 1 liter sample to raise the pH to 7.0. *ASSUME* the operator determines that *20 mg OF CAUSTIC* added to *1 LITER* of sludge raises the pH to 7.0. The quantity that must be added to the full-scale plant must be calculated according to the following solution.

Solution:

Known		**Unknown**
Aerobic Digester		Amount of Caustic (NaOH) to be added, lbs
pH down to	= 6.1	
Up pH to	= 7.0	
Digester Vol, gal	= 100,000 gal	
Jar Test Results, Caustic Added, mg/*L*	= 20 mg NaOH/*L*	

Determine the amount of caustic (NaOH) to be added in pounds.

$$\text{Caustic Added, lbs} = \frac{\text{NaOH to Jar, mg} \times \text{Dig Vol, gal} \times 3.78\ L/\text{gal}}{\text{Sludge Sample Vol, } L \times 454\ \text{gm/lb} \times 1000\ \text{mg/gm}}$$

$$= \frac{20\ \text{mg} \times 100{,}000\ \text{gal} \times 3.78\ L/\text{gal}}{1\ L \times 454\ \text{gm/lb} \times 1000\ \text{mg/gm}}$$

$$= 16.7\ \text{lbs NaOH}$$

If a significant rise in DO along with a decrease of O_2 uptake is definitely not being caused by low temperatures or low pH, the operator should check the sludge flow and volatile sludge solids loading to the digester during the previous seven days.

Excessive sludge flows will reduce the time of digestion and may increase the volatile sludge solids loading to the point where the digester is operating out of the recommended range of operation. The operator should adjust the flows and volatile sludge solids loading so as to operate within the range normally used for good operation.

The discussion thus far has dealt with a residual DO higher than normal, but the reverse may be noted. If the DO drops significantly, the operator should check the air rate and adjust as required to increase the residual DO to 1.0 to 2.0 mg/*L*. If higher than normal O_2 uptake rates are also noted, the operator should be aware that the volatile sludge solids loading rate to the digester may be higher than normal. As long as sufficient air capacity exists to meet air requirements at higher loading rates, the system can still operate but the operator should still check critical operating guidelines such as temperature, pH, and digestion time. If low DO exists and the blower is operating at full capacity, the operator should decrease the flow and loading to the digester or obtain additional blower capacity if the loadings cannot be decreased.

3.2241 Foaming. Aerobic digesters often develop foaming problems. If excessive foam develops, the operator should check the air rate and residual DO. If the DO is high and the remaining critical factors (O_2 uptake, pH, temperature) are satisfactory, the problem may be related to excessive turbulence. In this case, you should lower the air rate. If the DO is low, the operator should increase the air rate and observe a sample of digested sludge under a microscope. Low DO encourages filamentous growth. If filamentous growths are observed, the problem may be related solely to DO and the predominance of filamentous growths. On occasion, foaming will develop even with high DO. If this occurs, the problem may be related to influent characteristics and the operator should add defoaming agents to the digester to suppress the foam. Foaming in biological systems can be caused by a variety of conditions and generally indicates a rather complex problem. If the procedures given in this section will not cure a foaming problem, a consultant may be helpful.

3.2242 Loadings. Both the digestion time as governed by the hydraulic flow rate (GPD) and the volatile sludge solids loading (lbs VSS/day/cu ft) should be maintained in the ranges summarized in Table 3.8 (page 163). Operation outside of the recommended range may lead to decreased digester efficiency. A review of daily influent and effluent pounds of volatile sludge solids will indicate whether or not the digester is efficiently converting volatile (organic) matter to stabilized end products. A decrease in volatile suspended solids destruction should indicate to the operator that either digestion times are too short or volatile sludge solids loadings are too high.

Table 3.9 summarizes operational problems that may be encountered and corrective measures that might be taken.

TABLE 3.9 TROUBLESHOOTING AEROBIC DIGESTERS

Operational Problem	**Possible Causes**	**Check or Monitor**	**Possible Solutions**
1. High residual DO and normal uptake rate	1. High air rates	1. Air rate	1. Lower air rate
2. High residual DO and low uptake rate	2. a. Low digester temperature b. Low digester pH c. VSS loading too high or too low d. Digestion time too high or too low e. Toxicity	2. a. Temperature and heating equipment b. pH. Check for nitrification c. Flow rate and feed concentration d. Flow rate e. Toxic trace constituents in the influent sludge	2. a. Increase temp. b. Neutralize pH. Lower air rate & digestion time c. Adjust to obtain recommended loading d. Adjust to obtain recommended detention time e. Control of industrial waste discharges
3. Foaming	3. a. Filamentous growth b. Excessive turbulence	3. a. Residual DO and microscopic exam b. Air rate and residual DO	3. a. Increase air rate. Add defoamant b. Lower air rate. Add defoamant
4. Reduced VSS destruction	4. a. Low digestion time b. High VSS Loading c. Low temperature d. Low DO e. Low pH f. Toxicity	4. a. Flow & concentration of feed b. Same as 4. a. c. Temperature d. DO e. pH f. Toxic trace constituents in the influent sludge	4. a. Decrease flow b. Decrease flow c. Adjust temperature d. Increase air rate e. Neutralize pH f. Control industrial waste discharges
5. Poor settling sludge	5. Digestion time too high or too low	5. Flow rate and solids wasting	5. Run jar test to determine optimum dosage of alum, lime or polymer

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 252 and 253.

3.22N What routine checks can the operator make to indicate aerobic digestion process inefficiencies?

3.22O A 15,000 gallon aerobic digester has been operating successfully with a sludge flow of 1000 GPD. The influent sludge is normally at a concentration of 3.6 percent with a volatile content of 74 percent. The operator determines the residual DO in the digester to be 4.0 mg/*L*. Normally the digester operates at a DO of 1.5 mg/*L*. What should the operator do?

3.22P List the potential causes of foaming and the corrective measures that should be taken.

3.23 Chemical Stabilization

Sludges which are not biologically digested or thermally stabilized can be made stable by the addition of large dosages of lime or chlorine. *THE ADDITION OF LIME OR CHLORINE* to sludge to prepare it for ultimate disposal *IS NOT A COMMON PRACTICE.* Chemical addition is usually considered to be a *TEMPORARY STABILIZATION PROCESS* and finds application at overloaded plants or at plants experiencing stabilization facility upsets. The main drawback to chemical stabilization is the cost associated with the large quantities of chemical required.

3.230 Lime Stabilization

Lime stabilization is accomplished by adding sufficient quantities of lime to the sludge to raise the pH to 11.5 to 12.0. Estimated dosages to achieve a pH of 11.5 to 12.0 are generally 200 to 220 pounds of lime per ton for primary sludge solids (100 to 110 grams of lime per kg of solids). Waste activated sludge (WAS) will require doses from 400 to 800 pounds of lime per ton of sludge solids (200 to 400 grams of lime per kg of solids). An indication of the quantity required for a medium-size wastewater treatment plant is given in the following example.

EXAMPLE 26

Given: A 3.0 MGD secondary treatment plant produces 3,400 lbs/day of primary solids and 1,700 lbs/day of secondary sludge solids. Lime stabilization requires the addition of 210 lbs/ton to raise the pH to 12.0.

Find: The lbs of lime required per day.

Solution:

Known		**Unknown**
Secondary Treatment Plant		Lime Required, lbs/day
Flow, MGD	= 3.0 MGD	
Prim Sol, lbs/day	= 3,400 lbs/day	
Sec Sol, lbs/day	= 1,700 lbs/day	
To increase pH to 12.0, add lime, lbs/ton	$= \frac{210\text{ lbs lime}}{\text{ton Sl Sol}}$	

Calculate the amount of lime required in pounds of lime per day.

$$\begin{aligned}\text{Lime Req'd., lbs/day} &= \frac{\text{Dose, lbs lime}}{\text{Ton Sludge}} \times \frac{\text{Sludge, lbs/day}}{2000\text{ lbs/ton}}\\ &= \frac{210\text{ lbs lime}}{\text{Ton Sludge}} \times \frac{(3400\text{ lbs/day} + 1700\text{ lbs/day})}{200\text{ lbs/ton}}\\ &= 536\text{ lbs lime/day}\end{aligned}$$

An important consideration and drawback of lime stabilization is that the sludge mass is not reduced as with other stabilization processes (digestion, oxidation). In fact, the addition of lime adds to the overall quantity of solids that must be ultimately disposed.

3.231 Normal Operating Procedures

Lime as it arrives from the supplier in powder form cannot be added directly to sludge. The powdered lime must be made into a *SLURRY*[26] with the addition of water prior to blending with the sludge. Slurry concentrations (lb lime/gal water) are discussed in Section 3.3, "Conditioning." A lime stabilization system must incorporate the use of a slurry or mixing tank to mix the lime with water; a slurry transfer pump and a sludge mixing tank to mix the sludge and lime slurry. The process may be either continuous or batch and the slurry-sludge mixing tank must be of sufficient size to allow the mixture to remain at least 30 minutes at a pH of 11.5 to 12.0 before disposal. The pH of the slurry-sludge mixture should be measured either manually or automatically to ensure proper pH adjustment. The process of lime stabilization produces an unfavorable environment and destroys pathogenic and nonpathogenic bacteria. If the pH is not adjusted to the above range, the goals of stabilization will not be achieved.

3.232 Troubleshooting

The usual problem that is encountered with lime stabilization is improper pH adjustment and subsequent disposal of unstabilized sludge. Routine pH measurements on the slurry-sludge mixer will inform the operator of process inefficiencies. If the pH is lower than desired, the operator should check the slurry tank, slurry transfer pump and the flow and concentration of solids to the slurry sludge mixing tank. If an insufficient amount of lime was slurried or the slurry transfer pump is inoperative, the desired pH rise will not be acheived. If the lime slurry equipment and accessories are operating properly, the operator should check the flow rate and solids concentration to the mix tank. If either the flow or concentration is higher than normal, the total pounds of sludge solids also will be higher. In this case, the operator should increase the rate of flow of the lime slurrry to the mixing tank until the desired pH is obtained.

3.223 Chlorine Stabilization

Chlorine stabilization is accomplished by adding sufficient quantities of chlorine to the sludge to kill pathogenic and nonpathogenic organisms. Estimated dosages to achieve disinfection are generally 100 to 300 lbs chlorine/ton of sludge solids (50 to 150 gm chlorine/kg sludge solids). Waste activated sludge (WAS) requires higher doses than primary sludge. As is the case with lime stabilization, there is very little reduction of the sludge mass with chlorine stabilization. Therefore, the quantity of solids that remain for ultimate disposal are significantly greater than with digestion processes. The addition of the large quantities of chlorine required for stabilization will result in an acidic ($pH < 3.5$) sludge and neutralization with lime or caustic may be required prior to dewatering due to the corrosive condition of the mixture.

3.234 Normal Operating Procedures

Sludge to be treated enters the chlorine-sludge retention tank (Fig. 3.13) through a feed or recirculation pump. The retention tank is normally operated at a pressure of 35 to 45 psig (2.5 to 3.2 kg/sq cm) and detention times of 10 to 15 minutes. After leaving the reactor, the flow splits without about 10 percent discharged for further solids processing and 90 percent passing through an eductor and recycled back to the reactor. The passage of the sludge through the eductor creates a vacuum which causes the chlorine gas to move from the chlorine supply container into the sludge line.

Chlorine stabilization systems are completely automated with shutdown switches in the event of equipment malfunctions. The operator should refer to manufacturer's literature for routine operating procedures and troubleshooting techniques. In general, since these systems are fully automated, the operator need only be concerned with maintaining desired flows, replenishing chlorine supplies as needed, adjusting the chlorine addition rate, and checking equipment operation according to manufacturer's recommendations.

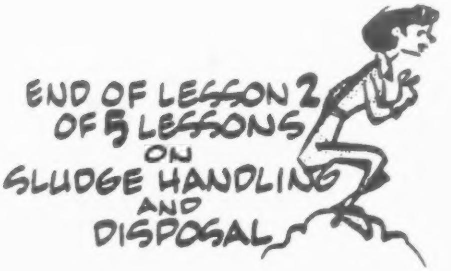
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 253.

3.23A List two chemicals used to stabilize sludges.

3.23B What are two major limitations of using chemicals to stabilize sludges?

3.23C Under what circumstances are chemicals most often used to stabilize sludges?



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[26] *Slurry (SLUR-e). A thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).*

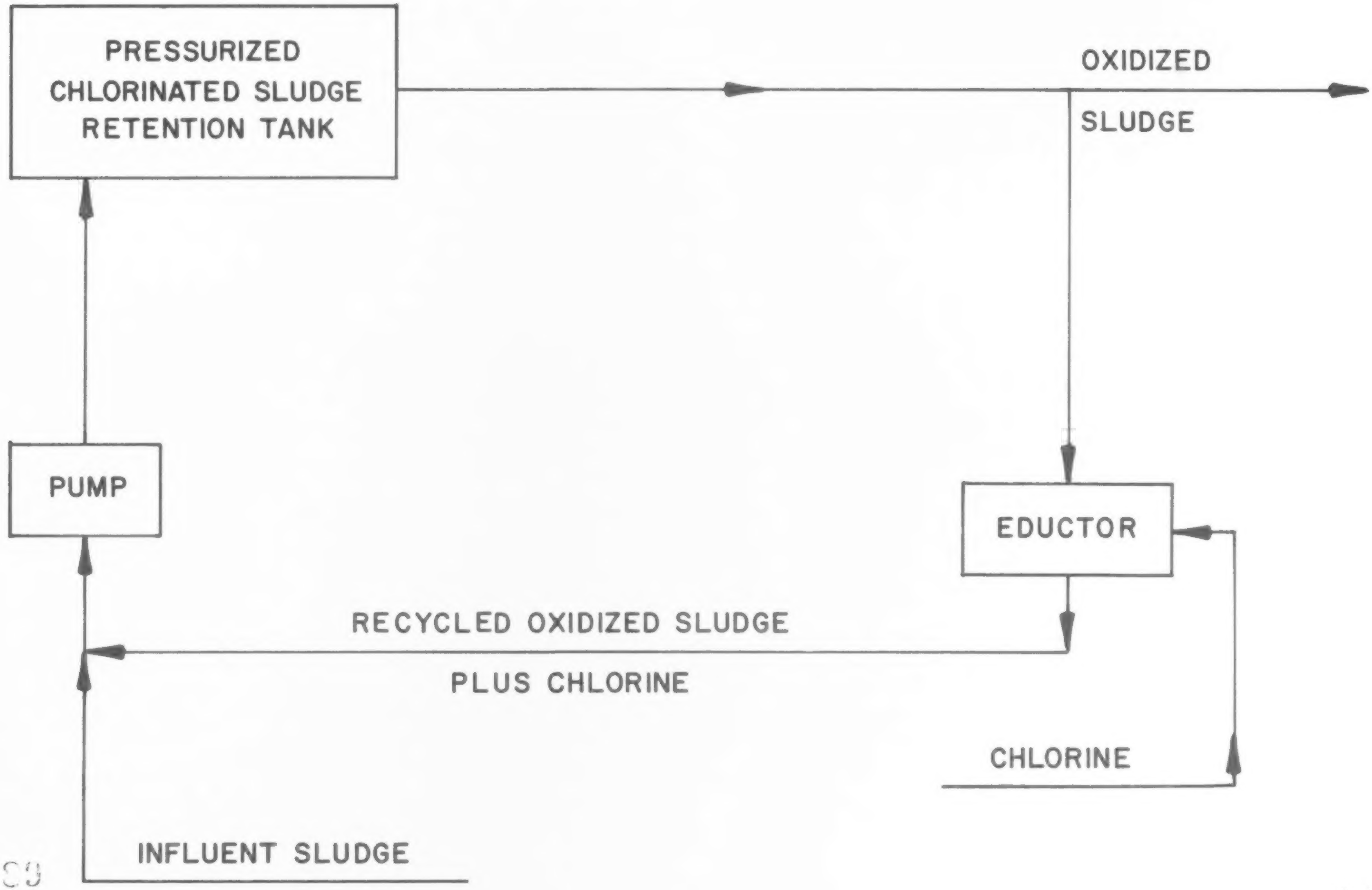
PRESSURIZED CHLORINATED SLUDGE RETENTION TANK
OXIDIZED SLUDGE
PUMP
EDUCTOR
RECYCLED OXIDIZED SLUDGE PLUS CHLORINE
CHLORINE
INFLUENT SLUDGE

Fig. 3.13 Sludge stabilization with chlorine

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 2 of 5 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1.

8. Why do wastewater treatment plant sludges have to be stabilized before disposal?
9. What variables affect the operation and performance of aerobic digesters?
10. What laboratory tests should be performed on aerobic digester influent and effluent samples?
11. What factors could upset an aerobic digester?
12. What problems are commonly encountered with the lime stabilization process?

CHAPTER 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 3 of 5 Lessons)

3.3 CONDITIONING

3.30 Purpose of Conditioning

Conditioning is defined as the pretreatment of sludge to facilitate the removal of water in subsequent treatment processes. Solid particles in sludge usually require conditioning because they are fine in particle size, hydrated (combined with water) and may carry an electrostatic charge. Sludge conditioning reduces mutually repelling electrostatic charges on suspended sludge particles, decreases the ability of biological sludges to entrain (hold) water and promotes *COAGULATION*[27] (gathering together) of the sludge solids. Sludge conditioning methods include: (1) chemical treatment, (2) thermal treatment, (3) wet oxidation, (4) *ELUTRIATION*[28] and (5) others such as freezing, electrical treatment and ultrasonic treatment. Of these, only chemical treatment, elutriation, thermal treatment and wet oxidation are practiced on a full-scale basis and the following discussion will focus on these four methods only.

3.31 Chemical Conditioning

The most commonly used chemical(s) for sludge conditioning is ferric chloride either alone or in combination with lime. In recent years, a group of synthetic organic chemicals, known as *POLYELECTROLYTES*[29] or polymers, have been developed and their use is rapidly gaining popularity and acceptance. Polymers are usually classified in three general types: anionic, cationic, or nonionic. Anionic polymers have a negative charge and are normally used as coagulant aids with positively charged alum and ferric chloride. Cationic polymers are positively charged and can serve as the sole coagulant or in combination with an inorganic coagulant such as alum. The use of cationic polymers is most common in sludge dewatering. Nonionic polymers are normally comprised of equal portions of cationic and anionic polymers, and have a charge that can vary with the pH of the solution. Nonionic, anionic and cationic polymers are all used as a coagulant aid. A seasonal fluctuation has been noted in chemical conditioning requirements so that many plants can successfully condition using cationic polymers during the summer and anionic polymers during the winter.

A detailed review of the chemistry involved when chemicals are used for conditioning is beyond the scope of this chapter. Essentially, the addition of chemicals reduces natural repelling forces and allows the solids to come together (coagulate) and gather (*FLOCCULATE*)[30] into a heavier solid mass.

The optimum chemical(s) type and dosage for a particular sludge is highly dependent on the characteristics of that sludge. Calculation of chemical requirements is usually based on *ON-SITE EXPERIMENTATION* and *TRIAL AND ERROR PROCEDURES*. This is because sludge types and characteristics vary from one treatment plant to the next and there is no one chemical or dosage that can be applied to all plants and sludges.

3.310 Chemical Requirements

In selection of chemical types and the determination of chemical requirements, it is important that the operator be very familiar with the selection procedures and be able to compare the efficiency and cost of one product or chemical with other products.

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[27] *Coagulation (co-AGG-you-LAY-shun). The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining, or filtering.*

[28] *Elutriation (e-LOO-tree-A-shun). The washing of digested sludge in plant effluent. The objective is to remove (wash out) fine particulates and/or the alkalinity in sludge. This process reduces the demand for conditioning chemicals and improves settling or filtering characteristics of the solids.*

[29] *Polyelectrolyte (POLY-electro-light). A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."*

[30] *Flocculation (FLOCK-you-LAY-shun). The gathering together of fine particles to form larger particles.*

Chemical requirements are usually determined by preliminary laboratory-scale "jar tests" (page 171) followed by pilot or full-scale trial experiments.

Jar tests are effective in indicating the *RELATIVE* quantity of chemical(s) required, but should be followed by on-site dewatering experiments to more accurately determine the required chemical dosage.

Chemicals are available in either liquid or solid (powder, crystals) form and the best way to equate one product to the next is to express the quantity required (lbs) per unit (tons) of dry sludge solids. The quantity required per unit of dry sludge solids (lb/ton) can then be multiplied by the chemical cost per pound ($/lb) to give you the cost in dollars per ton ($/ton) of sludge processed for each type of chemical.

EXAMPLE 27

Given: Jar tests indicate that a waste activated sludge flow of 30,000 GPD with a solids concentration of 1.5 percent sludge solids will require 18 pounds per day of Polymer A or 165 pounds per day of Polymer B for successful gravity thickening. Polymer A is a dry product and costs $2.00 per dry pound. Polymer B is a liquid product and costs $0.21 per liquid pound.

Find:
1. The polymer dosage in pounds polymer/ton of solids for Polymer A and Polymer B.
2. The unit cost in $/ton.

Solution:

Known		Unknown
Jar Tests on Waste Activated Sludge		1. Polymer dosage in lbs polymer per ton of solids for both Polymer A and B.
Flow, GPD	= 30,000 GPD	
Sl Sol, %	= 1.5%	
Polymer A, lbs/day	= 18 lbs/day	2. Unit cost in dollars per ton for both Polymer A and B.
Polymer B, lbs/day	= 165 lbs/day	
Polymer A, $/lb	= $2.00/dry lb	
Polymer B, $/lb	= $0.21/liquid lb	

1. Determine the polymer dosage in pounds of polymer per ton of sludge for both Polymer A and B.

   a. Calculate the tons of dry sludge solids per day treated by the polymers.

$$\text{Sludge, tons/day} = \frac{\text{Flow, GPD} \times 8.34 \frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}}{2000 \text{ lbs/ton}}$$

$$= \frac{30{,}000 \frac{\text{gal}}{\text{day}} \times 8.34 \frac{\text{lbs}}{\text{gal}} \times \frac{1.5\%}{100\%}}{2{,}000 \text{ lbs/ton}}$$

$$= 1.88 \text{ tons/day}$$

   b. Calculate the dosage for Polymer A in dry pounds of polymer per ton of sludge solids.

$$\text{Polymer A Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} = \frac{\text{Amount of Polymer A, lbs/day}}{\text{Sludge, tons/day}}$$

$$= \frac{18 \text{ lbs Polymer A/day}}{1.88 \text{ tons/day}}$$

$$= 9.6 \text{ lbs dry Polymer A/ton sludge}$$

   c. Calculate the dosage for Polymer B in liquid pounds of polymer per ton of sludge solids.

$$\text{Polymer B Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} = \frac{\text{Amount of Polymer B, lbs/day}}{\text{Sludge, tons/day}}$$

$$= \frac{165 \text{ lbs Polymer B/day}}{1.88 \text{ tons/day}}$$

$$= 88 \text{ lbs liquid Polymer B/ton sludge}$$

2. Determine the unit cost in dollars per ton for both Polymer A and B.

   a. Calculate the unit cost for Polymer A in dollars of polymer per ton of sludge solids treated.

$$\text{Unit Cost, \$/ton} = \text{Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{Polymer Cost, } \frac{\$}{\text{lb}}$$

$$= 9.6 \frac{\text{lbs polymer}}{\text{ton sludge}} \times \frac{\$2.00}{\text{lb polymer}}$$

$$= \$19.20\text{/ton of sludge}$$

   b. Calculate the unit cost for Polymer B in dollars of polymer per ton of sludge solids treated.

$$\text{Unit cost, \$/ton} = \text{Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{Polymer Cost, } \frac{\$}{\text{lb}}$$

$$= 88 \frac{\text{lbs polymer}}{\text{ton sludge}} \times \frac{\$0.21}{\text{lb polymer}}$$

$$= \$18.50\text{/ton of sludge}$$

This example illustrates the need to equate polymers on a cost per ton of solids ($/ton) basis rather than on a pound of product per ton of solids (lb/ton) basis. Even though more pounds of Product B were required, it yielded a lower cost than Product A.

Successful jar test and pilot or full-scale chemical addition requires that the chemicals be "prepared" prior to application. Liquid and powder or crystal polymers and lime must be mixed with water prior to using as a sludge conditioner. Ferric chloride can be added directly to sludge as it arrives in either bulk tanks or 55-gallon drums.

Typically, dry polymers are mixed with water to produce a solution strength of 0.05 to 0.25 percent. Liquid polymers are usually diluted to 1 to 10 percent polymer solutions as product, while lime is mixed to create 5 to 30 percent lime solutions. *THESE SOLUTION STRENGTHS ARE ALL BASED ON THE RATIO OF PRODUCT WEIGHT TO THE WEIGHT OF WATER.* Sample calculations to determine the pounds of product required per gallon of solution are illustrated below:

EXAMPLE 28

Given: Twenty five gallons of a 0.1 percent polymer solution is to be prepared by an operator at a wastewater treatment plant.

Find: The pounds of dry polymer to be added to the 25 gallons of water.

Solution:

Known		Unknown
Volume of Solution, gal	= 25 gal	Dry Polymer Added, lbs
Polymer Solution, %	= 0.1 %	

Determine the pounds of dry polymer to be added by setting up the problem as a proportion.

$$\frac{\text{Polymer Solution, \%}}{100\%} = \frac{\text{Dry Polymer, lbs}}{\text{Vol of Sol, gal} \times 8.34 \text{ lbs/gal}}$$

$$\frac{0.1\%}{100\%} = \frac{\text{Dry Polymer, lbs}}{25 \text{ gal} \times 8.34 \text{ lbs/gal}}$$

Rearrange the terms in the above equation and solve for the pounds of dry polymer.

$$\begin{aligned}\text{Dry Polymer, lbs} &= 25 \text{ gal} \times 8.34 \text{ lbs/gal} \times \frac{0.1\%}{100\%}\\ &= 0.21 \text{ lbs of Dry Polymer}\end{aligned}$$

In the above example, if 0.21 lbs of dry Polymer are mixed with 25 gallons of water, the solution strength would be 0.10 percent.

EXAMPLE 29

Given: Six pounds of dry polymer are added to 480 gallons of water.

Find: The strength of the polymer solution.

Solution:

Known	Unknown
Volume of Solution, gal = 480 gal	Strength of Polymer Solution, %
Dry Polymer Added, lbs = 6 lbs	

Calculate the strength of the polymer solution as a percent.

$$\begin{aligned}\text{Polymer Solution, \%} &= \frac{\text{Dry Polymer Added, lbs} \times 100\%}{\text{Vol of Sol, gal} \times 8.34 \text{ lbs/gal}}\\ &= \frac{6 \text{ lbs polymer}}{480 \text{ gal} \times 8.34 \text{ lbs/gal}} \times 100\ \%\\ &= 0.15\%\end{aligned}$$

EXAMPLE 30

Given: A lime solution is prepared by adding 250 pounds of lime to 100 gallons of water.

Find: The strength of the lime solution as a percent.

Solution:

Known	Unknown
Lime Solution	Strength of Lime Solution, %
Lime Dose, lbs = 250 lbs	
Water Volume, gal = 100 gal	

Calculate the strength of the lime solution as a percent.

$$\begin{aligned}\text{Lime Solution, \%} &= \frac{\text{Dry Lime Dose, lbs} \times 100\%}{\text{Volume of Water, gal} \times 8.34 \text{ lbs/gal}}\\ &= \frac{250 \text{ lbs lime}}{100 \text{ gal water} \times 8.34 \text{ lbs/gal}} \times 100\%\\ &= 30\%\end{aligned}$$

EXAMPLE 31

Given: Five gallons of a liquid polymer are added to 395 gallons of water.

Find: The strength of the polymer solution as a percent.

Solution:

Known	Unknown
Liquid Polymer, gal = 5 gal	Strength of Polymer Solution, %
Volume Water, gal = 395 gal	

Calculate the strength of the polymer solution as a percent.

$$\begin{aligned}\text{Polymer Solution, \%} &= \frac{\text{Liquid Polymer, gal} \times 8.34 \text{ lbs/gal}^{*} \times 100\%}{\text{Total Volume, gal} \times 8.34 \text{ lbs/gal}}\\ &= \frac{5 \text{ gal} \times 8.34 \text{ lbs/gal}}{(395 \text{ gal} + 5 \text{ gal}) \times 8.34 \text{ lbs/gal}} \times 100\%\\ &= 1.25\%\end{aligned}$$

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* Most liquid polymers are heavier than 8.34 lbs/gal.

The procedures for jar tests are outlined below and again, it should be noted that these tests only indicate the relative effectiveness of sludge conditioners. *JAR TESTS SHOULD BE FOLLOWED BY PILOT OR FULL-SCALE TESTS TO DETERMINE THE EXACT CHEMICAL REQUIREMENTS.*

JAR TEST PROCEDURE

1. Collect approximately one (1) gallon (approximately 4 liters) of a representative sample of sludge to be tested.
2. Prepare chemical solutions according to the manufacturer's recommendation. Only a small amount of chemical solution is needed for the jar test as compared with actual doses for wastewater being treated.
3. Save approximately ½ liter of the sludge sample for the sludge solids determination.
4. Fill a 1-liter beaker up to the 1-liter mark with the sludge to be tested.
5. Pipet a portion of the prepared chemical solution into the beaker containing the sludge. Polymer dosages should be increased by increments of 5 lbs/ton (2.5 gm/kg) or less for dry polymers, 25 lbs/ton (12.5 gm/kg) or less for liquid polymers, 100 lbs/ton (50 gm/kg) or less for ferric chloride and 200 lbs/ton (100 gm/kg) or less for lime.
6. After the chemical is placed in the beaker containing the sludge sample, the entire contents should be poured *SLOWLY* into a second 1-liter beaker and then poured slowly back to the original 1-liter beaker. This slow pouring action allows the chemical to mix with the sludge and coagulate and flocculate the sludge solids. If the chemical is effective, large floc particles will develop and free water will be observed. If the floc does not develop, add another portion of the chemical solution and slowly pour from one beaker to next. Continue adding portions of the chemical followed by gentle pouring until floc formation and clear water or a supernatant are observed.
7. Instead of pouring the chemical and sludge sample back and forth from one beaker to another, a stirring apparatus can be used as described in Chapter 23, Section 23.130, "Jar Test." The chemical mixing, flocculation, and settling conditions used in the jar test should be similar to the actual conditions in the treatment plant in order to obtain realistic results.
8. Record the volume of chemical solution required for floc formation.
9. After the solids analysis is performed on the initial sludge sample, determine the chemical dosage and associated costs.

The following example illustrates the incremental procedure and calculations for jar testing.

EXAMPLE 32

Given: A 1-gallon (4 liter) sample of digested primary sludge is to be collected and jar tests run using Polymer A, a dry polymer, and Polymer B, a liquid product. A ½-liter sample of the digested sludge was analyzed for suspended solids concentration. The sludge solids concentration was found to be 2 percent (20,000 mg/*L*).

Find: The quantity and approximate cost of Polymer A and Polymer B required.

Polymer Preparation: The solution to this problem is a series of jar tests. The first step is to prepare the polymer solutions. Polymer A is a dry polymer, therefore, mix a 0.05 to 0.25 percent solution. For jar tests, a 0.1 percent solution is desirable. Approximately 1 liter of solution should be prepared. The quantity of dry polymer to be added to 1 liter of water is determined based on the calculation in Example 29.

Solution:

Known	Unknown
Jar Tests Run on Polymers A and B	Quantity and Cost of Polymer A and Polymer B.
Sludge Solids, % = 2 % mg/*L* = 20,000 mg/*L*	
Polymer A is a dry powder 0.05 to 0.25 percent solution	
Polymer B is a liquid mix 1 to 10 percent solution	

$$1\text{ liter} = \frac{1\text{ liter}}{3.78\ L/\text{gal}} = 0.265\text{ gal}$$

To dose the jars, prepare 1 liter of a 0.10 percent solution of the dry polymer.

$$\begin{aligned}\text{Dry Polymer} &= \text{Volume, gal} \times 8.34\text{ lbs/gal} \times \frac{\text{Solution, \%}}{100\%}\\ &= 1\ L \times \frac{0.265\text{ gal}}{L} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{0.10\%}{100\%}\\ &= 0.0022\text{ lbs of dry polymer}\end{aligned}$$

Convert the dose in pounds to grams.

$$\begin{aligned}\text{Dry Polymer, grams} &= 0.0022\text{ lbs} \times 454\text{ grams/lbs}\\ &= 1.00\text{ grams}\end{aligned}$$

OR

Calculate the polymer dose in grams directly,

$$\begin{aligned}\text{Dry Polymer, grams} &= \text{Volume, } L \times \frac{1000\text{ gm}}{L} \times \frac{\text{Solution, \%}}{100\%}\\ &= 1\ L \times \frac{1000\text{ gm}}{L} \times \frac{0.10\%}{100\%}\\ &= 1.00\text{ grams}\end{aligned}$$

Therefore, 1.00 gram of dry polymer mixed with 1 liter of water will produce 0.10 percent polymer solution.

To dose the jars, prepare 1 liter of a 2.5 percent solution of the liquid polymer.

$$\begin{aligned}\text{Liquid Polymer, gal} &= \text{Volume, gal} \times \frac{\text{Solution \%}}{100\%}\\ &= 1\ L \times \frac{0.265\text{ gal}}{L} \times \frac{2.5\%}{100\%}\\ &= 0.0065\text{ gal}\end{aligned}$$

Convert the dose in gallons to milliliters.

$$\begin{aligned}\text{Liquid Polymer, ml} &= 0.0065\text{ gal} \times \frac{3780\text{ ml}}{\text{gal}}\\ &= 25\text{ ml}\end{aligned}$$

OR

Calculate the liquid polymer dose in milliliters directly,

$$\begin{aligned}\text{Liquid Polymer, ml} &= \text{Volume, } L \times \frac{1000\text{ ml}}{L} \times \frac{\text{Solution, \%}}{100\%}\\ &= 1\ L \times \frac{1000\text{ ml}}{L} \times \frac{2.5\%}{100\%}\\ &= 25\text{ ml}\end{aligned}$$

Determine the amount of water to be mixed with the liquid polymer.

$$\begin{aligned}\text{Volume Water, ml} &= \text{Total Volume, ml} - \text{Liquid Polymer, ml}\\ &= 1000\text{ ml} - 25\text{ ml}\\ &= 975\text{ ml}\end{aligned}$$

Therefore, 25 ml of liquid polymer mixed with 975 ml of water will produce a 2.5 percent solution.

Following polymer preparation, the jar tests should be conducted and the results recorded according to the following format:

	Polymer				
Sludge Type	**Type**	**Product Form**	**% Solution**	**ml Added**	**Observation**
Dig. Primary	A	dry	0.10	15	No floc formed
Dig. Primary	A	dry	0.10	30	Small floc formed
Dig. Primary	A	dry	0.10	50	Large floc and clear supernatant
Dig. Primary	B	liquid	2.5	15	No floc formed
Dig. Primary	B	liquid	2.5	30	Small floc formed
Dig. Primary	B	liquid	2.5	50	Large floc and clear supernatant

Based on the amount of polymer added and the observations made for the above tests, approximately 50 ml of Polymer Solution A and 50 ml of Polymer Solution B are required to coagulate and flocculate the solids. The dosage (lb/ton) can then be calculated as follows:

POLYMER A (DRY)

Determine the dosage of Polymer A in pounds of polymer per ton of sludge solids treated.

$$\text{Dosage, }\frac{\text{lbs}}{\text{ton}} = \frac{\dfrac{\text{Sol, \%}}{100\%} \times \underset{\text{(Added)}}{\text{Polymer, ml}} \times \dfrac{1\text{ gal}}{3780\text{ ml}} \times \dfrac{8.34\text{ lbs}}{\text{gal}} \times \dfrac{2000\text{ lbs}}{\text{ton}}}{\text{Sl Vol, } L \times \dfrac{1\text{ gal}}{3.78\ L} \times 8.34\ \dfrac{\text{lbs}}{\text{gal}} \times \dfrac{\text{Sl Sol, \%}}{100\%}}$$

By cancelling out similar terms, the equation can be reduced to:

$$\begin{aligned}\text{Dosage, }\frac{\text{lbs}}{\text{ton}} &= \frac{\text{Sol, \%} \times \text{Polymer Added, ml}}{\text{Sl Vol, } L \times \text{Sl Sol, \%}} \times 2\\ &= \frac{0.10 \times 50 \times 2}{1.0 \times 2.0}\\ &= 5\text{ lbs dry Polymer/ton sludge solids}\end{aligned}$$

POLYMER B (LIQUID)

$$\text{Dosage}, \frac{\text{lbs}}{\text{ton}} = \frac{\text{Sol, \%} \times \text{Polymer Added, ml}}{\text{Sl Vol}, L \times \text{Sl Sol, \%}} \times 2$$

$$= \frac{2.5 \times 50}{1.0 \times 2.0} \times 2$$

$$= 125 \text{ lbs liquid Polymer/ton sludge solids}$$

Calculate the cost per ton to use Polymer A if the dry Polymer costs $2.00 per pound.

$$\text{Cost}, \frac{\$}{\text{ton}} = \frac{5 \text{ lbs Polymer}}{\text{ton sludge solids}} \times \frac{\$2.00}{\text{lb Polymer}}$$

$$= \$10/\text{ton sludge solids}$$

Calculate the cost per ton to use Polymer B if the liquid Polymer costs $0.21 per pound.

$$\text{Cost}, \frac{\$}{\text{ton}} = \frac{125 \text{ lbs Polymer}}{\text{ton sludge solids}} \times \frac{\$0.21}{\text{lb Polymer}}$$

$$= \$26.25/\text{ton sludge solids}$$

Based on these jar tests, Polymer A would cost about one half as much as Polymer B.

Following jar test experiments, the polymer or any other chemical should be evaluated on pilot or full-scale equipment. The determination of polymer dosages is identical to calculations used for the jar test examples except that larger values of chemical and sludge are used. The following example illustrates the calculation on a full-scale basis.

EXAMPLE 33

Given: A waste activated sludge flow of 200 gpm at 0.90 percent (9000 mg/*L*) solids is to be conditioned with 20 gpm of a 0.05 percent dry polymer solution.

Find: The pounds of dry polymer to be mixed with 5000 gallons of water to produce a 0.05 percent solution and the resulting dosage in lbs/ton.

Solution:

Known

Waste Activated Sludge
Sludge Flow, GPM = 200 GPM
Sl Sol, % = 0.90%
, mg/*L* = 9,000 mg/*L*
Polymer Flow, GPM = 20 GPM
Polymer Solution, % = 0.05%

Unknown

1. Pounds of dry polymer to be mixed with 5000 gallons to produce a 0.05 percent polymer solution.
2. Dosage in pounds polymer per ton of sludge solids.

1. Determine the pounds of dry polymer to be mixed with 5,000 gallons to produce a 0.05 percent polymer solution.

$$\begin{array}{l}\text{Dry Polymer}\\ \text{Required, lbs}\end{array} = \frac{\text{Polymer Sol, \%} \times \text{Vol, gal} \times 8.34 \text{ lbs/gal}}{100\%}$$

$$= \frac{0.05\% \times 5000 \text{ gal}}{100\%} \times \frac{8.34 \text{ lbs}}{\text{gal}}$$

$$= 20.9 \text{ lbs}$$

2. Calculate the dosage in pounds of polymer per ton of sludge solids.

$$\text{Dosage}, \frac{\text{lbs}}{\text{ton}} = \frac{\text{Sol, \%} \times \text{Polymer Added, GPM}}{\text{Sl Flow, GPM} \times \text{Sl Sol, \%}} \times \frac{2000 \text{ lbs}}{\text{ton}}$$

$$= \frac{0.05\% \times 20 \text{ GPM}}{200 \text{ GPM} \times 0.9\%} \times \frac{2000 \text{ lbs}}{\text{ton}}$$

$$= 11.1 \frac{\text{lbs polymer}}{\text{ton sludge solids}}$$

An extensive amount of time and discussion was devoted to the determination of chemical solution requirements and chemical dosages because many times the proper amount(s) of chemicals are not added in routine operation. In order to chemically condition sludge at the required dosage, the operator must be able to determine the quantity to be prepared and added to the sludge.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 253 and 254.

3.30A Why do solid particles present in sludge usually require conditioning?

3.30B List the different types of conditioning methods available.

3.31A Briefly explain how chemical addition conditions sludge.

3.31B Explain why chemical types and dosage requirements vary from plant to plant.

3.31C Briefly explain how chemical requirements are determined for a particular sludge.

3.31D Three pounds of dry polymer are added to 360 gallons of water. What is the solution strength of the mixture?

3.31E Ten pounds of lime are added to 100 gallons of water. What is the solution strength of the mixture?

3.31F Ten gallons of liquid polymer are added to 790 gallons of water. What is the solution strength of the mixture?

3.31G Five gallons of commercially available ferric chloride is added to 50 gallons of water. What is the solution strength of the mixture?

3.31H A jar test has been conducted on digested primary sludge. The sludge has a concentration of 3.0 percent SS (30,000 mg/*L*) and 60 ml of a 0.15 percent solution of polymer was required to flocculate the sludge. Determine the polymer dosage in lbs/ton and the cost in $/ton if the polymer costs $1.50/lb.

3.31I A polymer solution of 2.5 percent is prepared from a liquid polymer and added at a rate of 3 GPM to a sludge flow of 30 GPM. The sludge has a solids content of 4 percent sludge solids. Determine the dosage (lbs/ton) and the cost ($/ton) if the liquid polymer costs $.20/lb.

3.311 Chemical Solution Preparation

ONE OF THE KEYS TO SUCCESSFUL CHEMICAL CONDITIONING IS THE PREPARATION OF THE CHEMICAL SOLUTION. Depending on the solution strength to be made, the proper amount (lbs) of dry polymer or lime must first be weighed out and then added to a predetermined amount of water and mixed. *THE WEIGHING CONTAINER SHOULD BE DRY, AND THE DRUMS OR BULK STORAGE TANKS OF DRY CHEMICALS SHOULD NOT BE ALLOWED TO ABSORB MOISTURE.* If these chemicals are stored in a dry place, there should be no problems with handling and transferring to a weighing container. If the chemicals absorb moisture or become wet, balls or cakes of chemicals will form and prevent easy handling and transferring.

If the quantity of chemical used exceeds approximately 25 to 50 lbs per day (11 to 22 kg/day), automatic chemical feed systems are commonly used. Such equipment usually includes a storage hopper to hold bulk supplies of the chemical and a screw conveyor system to measure out and transfer the dry chemical to the mixing chamber. These automatic systems are usually activated by liquid-level indicators in the mixing tank. When the liquid level falls below the bottom probe, a signal is automatically sent and water is delivered to the mix tank. After the water level reaches a predetermined point, a second signal activates the screw conveyor system and dry chemical is delivered to the tank. The length of time the screw feeder is operated depends on the number of pounds per minute the feeder can deliver to the mix tank, the solution desired, and the volume of the mix tank. The most common problems encountered with automatic feed systems are plugging of the screw conveyor and the build up of chemicals at the discharge side of the screw. These problems can usually be traced back to premature wetting of the chemicals by water sprays coming from the mix tanks or from not having a water tight storage and feed system. If moisture can be prevented from entering the storage hopper and screw conveyor, smooth operation should result. Lime is somewhat easier to put into solution than dry polymers. Automatic dry polymer feed systems are sometimes equipped with wetting mechanisms to prewet the polymer as it falls into the mix tank. If the polymer is not properly wet as it falls into the mix tank, a poor mix will result and will be evident by balls or "fish eyes" of undissolved polymer in the tank. Another method of mixing dry polymers is to use an aspirator or *EDUCTOR*[31] to put the dry polymer into solution.

For smaller systems requiring less than 25 to 50 lbs/day (11 to 22 kg/day), manual batching can successfully be used. The procedure to prepare and apply batch chemicals manually is as follows:

1. Weigh out the desired quantity of dry product in a dry container.
2. Partially fill the mix tank with water until the impellers on the mixer are submerged.
3. Turn on the mixer.
4. Add the premeasured dry product to the mix tank. Lime can be poured directly into the tank. Dry polymers have to be added through an eductor for wetting purposes.
5. Fill the tank to the desired level.
6. Allow tank contents to mix thoroughly before use to sufficiently "cure" the solution.
7. Turn off the mixer.

The curing or mixing time after the dry chemical has been added to the tank should be 45 to 60 minutes for polymers and approximately 30 minutes for lime. If adequate mixing times are not allowed for curing, the chemical will not be as effective as it should be because it will not fully dissolve and chemical requirements for successful conditioning will increase.

The preparation of chemical solutions from liquid polymers and liquid ferric chloride is not as difficult as for dry polymers and lime because these liquids go into solution more rapidly and prewetting is not required.

Automatic batching systems are commonly used for handling quantities in excess of 55 gallons/day (208 liters/day) of product. These systems incorporate the use of bulk storage tanks, bulk solution transfer pumps and mixing tanks. Manual preparation incorporates the same procedures outlined for dry chemicals except that eductors are not used and the curing time can usually be reduced to approximately 20 to 30 minutes.

After the chemicals are cured, they can either be pumped to another tank or pumped to the sludge stream to be conditioned. The use of a second holding tank provides for a mix tank to be available at any time to prepare another batch of chemicals. Both the mix tank and transfer tank, if used, should be covered and protected from the sun's rays and extreme heat. Covering of the tanks should prevent foreign material from entering and possibly clogging equipment. When polymers are used, covering should be mandatory because the ultraviolet sun rays deteriorate the polymer molecules and can rapidly decrease the effectiveness of the solution. The same is true if the tank contents are allowed to approach temperatures of 120 to 130°F (49 to 54°C). At these temperatures, the polymer molecules can be broken down and the effectiveness of the solution deteriorates. To ensure protection against ultraviolet rays and extreme heat, all chemical tanks should be covered and insulated or painted white to reflect heat.

3.312 Chemical Addition

Once the chemical has been prepared and the approximate dosage and addition rate determined, the solution can be added to the sludge for conditioning. The point(s) of application for the different chemicals will vary and is dependent on the chemical type and the specific mechanical equipment (DAF, centrifuges) used. In general, polymers are added directly into the feed assemblies of the various equipment types. Polymers should not be added to the suction side of sludge feed pumps because the shearing forces through such pumps tend to shear any floc formation. After conferring with the equipment and polymer manufacturers, application points for polymers should be determined by field experimentation. The use of lime and ferric chloride generally requires a blending tank to mix these chemicals with the sludge prior to dewatering. Lime and ferric chloride are generally not used for DAF thickening or centrifugation. Their use is usually limited to gravity thickening and vacuum and pressure filtration. Again, application points and blending requirements can best be determined by field experimentation and discussions with the equipment and chemical manufacturers.

3.313 Typical Chemical Requirements

Table 3.10 summarizes typical chemical dosages required for various sludge types. Remember that the actual chemical requirements vary not only with the actual sludge, but also with the dewatering device. The optimum chemical dosage(s) is usually determined by on-site experimentation.

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[31] *Eductor (e-DUCK-tor). A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a suction pump.*

TABLE 3.10 TYPICAL CHEMICAL CONDITIONING REQUIREMENTS[a]

Sludge Type	Ferric Chloride, lbs/ton[b]	Lime, lbs/ton[b]	Polymer, lbs/ton[b]
Primary	20 - 40	120 - 200	4 - 24
Primary, WAS	30 - 50	140 - 180	10 - 20
WAS	80 - 200	-	4 - 30
Digested Primary	30 - 100	300 - 600	5 - 40
Digested Primary and WAS	30 - 200	300 - 600	15 - 50
Digested WAS	80 - 200	300 - 600	15 - 40
Digested Elutriated Primary	40 - 80	-	10
Digested Elutriated Primary and WAS	40 - 80	-	15 - 30

[a] *SLUDGE PROCESSING AND DISPOSAL: A STATE OF THE ART REVIEW*, LA/OMA Project, County Sanitation Districts of Los Angeles County, Whittier, California, April 1977.

[b] Expressed as pounds of chemical/ton of dry sludge solids. lbs/ton × 0.5 = gm of chemical/kg of dry sludge solids.

3.314 Troubleshooting

If decreases in thickening and/or dewatering equipment performance cannot be traced to equipment malfunctions, then the operator should check the chemical mixing (preparation) and addition equipment. With automatic feeding systems, the operator should check (1) the level of dry product in the storage hopper and replenish if necessary, (2) the screw conveyor and unplug if necessary, (3) the quality of the solution (are there large balls of undissolved chemical?), and (4) the chemical addition pump. Many times these chemical pumps are allowed to run dry due to inoperative level indicators and shut off mechanisms. If pumps are run dry, the interior components may wear and the pump will not deliver at its rated capacity. The operator should recalibrate the chemical feed pump and repair if necessary, because the pump may be the only means of measuring the chemical feed rate. The best indication of a failure in the chemical preparation and/or the chemical feed rate is to run a jar test on the sludge with a laboratory prepared batch of the chemical. If these jar tests indicate substantially less polymer than that supposedly added at full scale, there is usually a problem with the quality of the full-scale solution or the application rate.

Table 3.11 summarizes the problems that may arise during chemical conditioning and the action that might be taken.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 254.

3.31J Why should dry chemicals be kept in a dry place?

3.31K What is the purpose of wetting dry polymers?

3.31L Outline the procedures to prepare a batch solution of dry and liquid chemicals.

3.31M Why is curing time important?

3.31N Why should chemical tanks be covered?

3.31O Why are polymers generally not added to the suction side of sludge pumps?

3.31P Outline the areas to be checked if sludge thickening or dewatering inefficiencies cannot be traced back to equipment failures.

3.32 Thermal Conditioning

Wastewater sludges, and biological sludges in particular, may have large quantities of bound water associated with them. The cell mass of biological sludges contains water along with other soluble and particulate matter. Outside the cell wall is a gelatinous sheath (cover) composed of *PROTEINACEOUS*[32] and *POLYSACCHARIDE*[33] material along with an additional quantity of water referred to as "bound water." Subjecting these sludge particles to extreme heat at elevated pressures hydrolizes (decomposes) the surrounding sheath and bursts the cell wall allowing bound water to escape. The net effect of releasing the cell water is a substantial increase in the dewaterability of the sludge.

When used for conditioning, thermal treatment facilities are usually operated in the heat treatment or low pressure wet oxidation (LPO) modes. The process descriptions for heat treatment and LPO conditioning are basically identical to that for the wet oxidation process outlined in Section 22.33. The major differences are that (1) air is not introduced into the reactor for heat treatment conditioning and only a limited or small quantity of air is introduced for LPO conditioning and (2) the reactor temperatures are lower than those sustained for wet oxidation. Reactor temperatures for heat treatment and LPO conditioning are typically 350°F to 400°F (177°C to 204°C) with reactor detention times of 20 to 40 minutes.

TABLE 3.11 TROUBLESHOOTING CHEMICAL CONDITIONING PROCESSES

Problem	Possible Causes	Check or Monitor	Possible Solutions
Effluent quality and/or sludge concentrations from thickening or dewatering equipment deteriorating	1. Poor solution mixture	1a. Automatic feed system 1b. Mixer operation 1c. Run jar test on sludge with a fresh laboratory solution of chemical	1a. Fill storage hoppers and batch tanks 1b. Allow for adequate curing time 1c. Batch a new supply of chemicals
	2. Chemical dosage inadequate	2. Chemical feed pump operation.	2. Turn on pump, open appropriate valves. Calibrate pump and increase rate or solution strength of the chemical.

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[32] *Proteinaceous (PRO-ten-NAY-shus). Materials containing proteins which are organic compounds containing nitrogen.*

[33] *Polysaccharide (polly-SAC-a-ride). A carbohydrate such as starch, insulin or cellulose.*

3.320 Factors Affecting Thermal Conditioning

The performance and efficiency of thermal conditioning systems are dependent on: (1) the concentration and consistency of the influent sludge, (2) reactor detention times, and (3) reactor temperature and pressure. For conditioning purposes, the introduction of relatively small quantities of air (LPO) results in little, if any, difference in sludge dewaterability. The advantage usually associated with adding air is a reduction in fuel requirements because of increased thermal efficiencies within the reactor. This potential fuel savings may be offset by the power requirements needed to supply the air. For all practical purposes, however, heat treatment and LPO conditioning will be regarded as equivalent in this discussion.

The solids concentration of the influent sludge will have significant effects on the overall heating requirements and the reactor detention times. The physical size of thermal conditioning systems is based on hydraulic and solids loadings. If the concentration of the influent sludge decreases significantly, the volume of water pumped to the reactors will increase. This will cause a decrease in the detention time within the reactor and an increase in the heating requirements due to the increased water volume. The following example illustrates the effect(s) that sludge concentration has on operation of thermal systems.

EXAMPLE 34

Given: A thermal conditioning system is designed to process 200 GPM of waste activated sludge at a concentration of 3.5 percent. The thermal reactor has a volume of 8,000 gallons.

Find: 1. The reactor detention time under design conditions.

2. The reactor detention time if the sludge enters at a concentration of 2.5 percent.

3. The effect of reduced concentration on heat requirements.

Solution:

Known		Unknown
Thermal Conditioning System		1. Reactor Detention Time
Treat Waste Activated Sludge		2. Reactor Detention Time if Solids at 2.5%
WAS Flow, GPM	= 200 GPM	
Reactor Vol, gal	= 8000 gal	3. Effect of 2.5% Solids on Heat Requirements
Sludge Solids, %	= 3.5%	

1. Calculate the reactor detention time in minutes.

$$\text{Detention Time, min} = \frac{\text{Reactor Volume, gal}}{\text{Flow, GPM}}$$

$$= \frac{8000 \text{ gallons}}{200 \text{ gal/min}}$$

$$= 40 \text{ min}$$

2. Calculate the reactor detention time if the sludge solids concentration drops from 3.5% to 2.5%. A reduction in solids concentration causes an increase in WAS flow.

$$\text{New Flow, GPM} = \text{Old Flow, GPM} \times \frac{\text{Old Sl Sol, \%}}{\text{New Sl Sol, \%}}$$

$$= 200 \text{ GPM} \times \frac{3.5\%}{2.5\%}$$

$$= 280 \text{ GPM}$$

$$\text{Detention Time, min} = \frac{\text{Reactor Volume, gal}}{\text{Flow, GPM}}$$

$$= \frac{8000 \text{ gallons}}{280 \text{ gal/min}}$$

$$= 29 \text{ min}$$

3. What is the effect on heat requirements of a decrease in WAS concentration from 3.5% to 2.5% sludge solids?

A specific amount of heat is required to raise a volume of water from one temperature level to the desired level. If the volume of water increases (as it will when WAS concentration drops to 2.5% sludge solids), the amount of heat required to raise the temperature of the increased volume of water also increases.

In the above example, the reactor detention time decreased from 40 minutes to 29 minutes when the sludge concentration decreased from 3.5 to 2.5 percent. This is not necessarily desirable. In general, as the reactor detention time increases from 20 to 40 minutes, the dewaterability of the sludge also increases somewhat and it is important to *CONSISTENTLY PUMP A THICKENED SLUDGE* to the thermal unit to ensure effective and efficient operation.

The temperature and pressure within the reactor also contributes to the degree of conditioning obtainable. As the reactor temperature is increased from 350 to 400°F (177 to 204°C), the general trend is an increase in the dewaterability of the conditioned sludge. Pressures are increased with temperature to prevent sludge from boiling so these two factors are dependent on each other.

3.321 Operating Guidelines

The key operating guidelines that the operator has some control over on a day-to-day basis are: (1) inlet sludge flow, (2) reactor temperature and detention time, and (3) sludge withdrawal from the decant tank.

As discussed, the inlet sludge flow and reactor detention time are dictated by the concentration of the thickened feed sludge and the total pounds of solids processed. If the operator maintains a consistently thick feed by closely monitoring and operating the thickening equipment, the sludge inlet volume will be minimized, reactor detention times will be maximized, and optimum thermal conditioning should result. The control of reactor temperature between the normal range of 350 to 400°F (177 to 204°C) will depend on how the sludge dewaters in subsequent dewatering facilities. In general, the sludge dewaters better following conditioning at higher temperatures but the temperature should be maintained so as to achieve the desired dewatering results. The degree of dewatering required will vary from one treatment plant to the next and the operator should maintain operating temperatures according to the dewaterability desired and achieved. If it is found that a reactor temperature of 350°F (177°C) provides sufficient conditioning to satisfy the dewatering requirements, the operator should not increase the conditioning temperature. If on the other hand, a temperature of 350°F (177°C) is not adequate from a dewatering standpoint, the operator should increase the reactor temperature. Any decisions to vary reactor temperatures and/or pressures should be based on consultation between the operator and supervisors.

The operator also has the ability to control the concentration of the underflow solids from the decant tank by controlling the rate of sludge withdrawal. The decant tank is a gravity thickener and the same operating procedures outlined in Section 22.1 should be applied in operating the decant tank. In most instances, gasification is not a problem in thermal conditioning decant tanks because of the lack of biological activity. The high temperatures sustained in the thermal reactors should sterilize the sludge and biological activity with subsequent gas production should not occur.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 254.

3.32A Briefly explain how thermal conditioning improves the dewaterability of sludge.

3.32B List the factors that affect thermal conditioning.

3.32C Determine the reactor detention time for a reactor volume of 1,000 gallons and a sludge flow of 33 GPM with a concentration of 4.0%.

3.32D If the sludge concentration from problem 22.32C decreases to 2.5%, determine the reactor detention time assuming the same total pounds are processed.

3.32E Briefly discuss the operating controls available to optimize thermal conditioning facilities.

3.32F Why is gasification not usually a problem with gravity thickening of thermally treated sludge?

3.322 Normal Operating Procedures

Thermal conditioning units can be operated in the continuous or batch modes. Continuous operation is the preferred mode because energy is not wasted in allowing the heat exchanger and reactor contents to cool down and be heated back to the desired temperature each day when operated as a batch process.

Under the batch operation mode the following steps should be followed:

1. Fill the reactor and heat exchangers with water if the water is drained after the previous day's shutdown.
2. Turn on the boiler make-up water pump and open valve to the steam boiler.
3. Open the required steam valves to the thermal reactor and start the boiler.
4. After the reactor has reached its desired operating temperature, open the sludge inlet and outlet valves.
5. Turn on the sludge grinder and the stirring mechanism in the decant (gravity thickener) tank.
6. Turn on the vent fan from the decant tank and activate the appropriate odor-control equipment.
7. Turn on sludge feed pump. If LPO conditioning is used, turn on air compressor.

The above procedures should be followed in reverse for shutdown operation. For continuous operation, these procedures are followed whenever the operation is interrupted for mechanical or routine shutdowns.

Whether operating in the continuous or batch mode, fuel levels for the steam generating system should be routinely checked and replenished as required and daily records of the pressure drop across the heat exchangers should be kept. The heat exchangers are subject to clogging due to the formation of scale. Periodic acid flushings are therefore required to remove these deposits and to unplug the heat exchangers. The best indication of scaling and the time at which an acid flushing should be conducted is the pressure drop across the heat exchangers. Pressure drop is determined by measuring the pressures at the heat exchanger inlet and outlet and calculating the pressure differential (Δp) according to the following equation:

$$\Delta p = P\text{ outlet} - P\text{ inlet}$$

When the pressure difference (Δp) reaches a certain magnitude, the system should be taken out of service and an acid flushing should be done. The pressure drop at which an acid flushing is required is determined by the manufacturer and in no case should the pressure differential be allowed to develop beyond the manufacturer's recommended figure. Routine and/or periodically required acid flushings should be conducted according to the manufacturer's procedure.

3.323 Typical Performance

Typical operating guidelines are presented in Table 3.12. The overall evaluation of thermal performance is based on subsequent mechanical dewatering of the conditioned sludge. Performance data for various conditioning and dewatering schemes will be presented in Section 3.4. The degree of dewatering obtainable is indicated in Table 3.12 from a qualitative standpoint.

TABLE 3.12 DEGREE OF DEWATERING FROM VARIOUS SLUDGE TYPES

		Reactor			
Sludge Type	Thermal Mode	°F[a]	PSIG[b]	Detention Time, Min	Dewaterability
Primary	LPO or HT	350-400	350-400	20-60	Excellent
Secondary	LPO or HT	350-400	350-400	20-60	Good-Excellent
Dig. Primary	LPO or HT	350-400	350-400	20-60	Good-Excellent
Dig. Primary & Secondary	LPO or HT	350-400	350-400	20-60	Good

[a] (°F − 32°F) × 5/9 = °C
[b] psi × 0.07 = kg/sq cm

3.324 Troubleshooting

Thermal conditioning systems are high temperature and high pressure processes and incorporate the use of sophisticated instrumentation and mechanical equipment. All of the mechanical, electrical, and performance difficulties that might arise cannot be summarized in this section. In the event of complicated mechanical and/or electrical malfunctions, the operator should not attempt to locate and/or to correct these problems without the assistance of qualified mechanics, electricians, or instrument personnel. The following discussion will be limited to malfunctions typically encountered on a day-to-day basis.

3.3240 Reactor Temperature. If the reactor temperature cannot be maintained at the desired temperature, the operator should check: (1) the fuel supply to the steam boiler, (2) temperature sensor and boiler accuator assembly, and (3) boiler make-up water supply. If the boiler fuel system and make-up water supply are adequate but the reactor temperature fluctuates significantly, the problem may be related to instrumentation malfunctions and the operator should seek the assistance of qualified electricians or instrumentation personnel.

3.3241 Reactor Pressure. If the high pressure feed pump is inoperative, the desired pressure will not be maintained. The usual problem with the feed pump is loss of prime due to a plug on the suction side or clogging of the sludge guide. Loss of prime will result in low or no flow through the system.

3.3242 Heat Exchanger Pressure Differential. Increases in the pressure drop across the heat exchangers indicates the buildup of scale. In the event of an excessive pressure drop, the operator should schedule a shutdown and acid flush the system according to the manufacturer's recommended procedure.

3.3243 Sludge Dewaterability. A decrease in the dewaterability of the thermally conditioned sludge may be attributed to operational difficulties with the specific dewatering equipment and/or the maintenance of less than optimum thermal conditioning criteria. If the deterioration in dewaterability cannot be attributed to dewatering equipment inefficiencies, the operator should check: (1) the flow rate through the thermal system, (2) reactor temperature, and (3) operation of the decant (gravity) thickener.

An increase in the flow rate due to introducing a thin feed sludge will result in decreased reactor detention times and possible decreases in dewaterability.

If the problem is attributed to low reactor detention times, the operator should check and optimize the sludge thickening equipment. Decreases in reactor temperatures will also result in inferior dewatering characteristics and the operator should check and adjust the temperature as required.

The operation of the decant tank will also affect dewaterability. In general, the operator should provide for as thick a decant underflow sludge as possible to the dewatering facility. This is controlled by monitoring and controlling the underflow sludge withdrawal rate. Be careful that the sludge does not become so heavy that it cannot be moved out of the decant tank. Decant stirring plows should be operated continuously. Operation of the decant tank should follow the same procedures outlined for gravity thickeners.

Table 3.13 summarizes operational problems that might be encountered and criteria that should be checked.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 254 and 255.

3.32G Why is continuous operation of a heat treatment unit desirable?

3.32H Outline the start-up and shutdown procedures for a heat treatment unit.

3.32I Why should a log be kept on the pressure drop across the heat exchangers and what action should be taken to correct excessive pressure drops?

3.32J Over the course of a week, the dewaterability of a thermally conditioned sludge decreases drastically. What operating criteria should be checked and what corrective measures can be taken?

3.33 Wet Oxidation

Wet oxidation is a thermal treatment process that stabilizes organic matter and results in a net reduction in the sludge mass and a total destruction of pathogenic organisms.

Three modes of wet oxidation exist: low-pressure wet oxidation (LPO), intermediate-pressure wet oxidation (IPO), and high pressure wet oxidation (HPO). Figure 3.14 is a schematic of the process. Sludge to be processed is first passed through a grinder to reduce the particle size of the sludge solids and thereby reduce the potential for clogging inside the wet oxidation unit. The sludge may then be pumped to the oxidation unit by a high-pressure positive-displacement pump along with air which is supplied by an air compressor. A high-pressure feed pump is used to produce and maintain required pressures in the oxidation unit. Sludge and air are then passed through heat exchangers and delivered to the thermal reactor. Stabilization takes place within the reactor. The stabilized sludge leaving the reactor is cooled in the heat exchangers against the entering cold sludge and then released to a decant (gravity) thickener for separation and compaction of the stabilized sludge solids. Off gases from the decant tank are vented to gas scrubbers and carbon adsorbers or to a catalytic combustion unit for odor control. Overflow from the decant tank may be returned to the plant headworks while the underflow (thickened) solids are pumped to subsequent dewatering units. The decant tank overflow may require additional treatment prior to recycling to the plant headworks. Heat is added to the reactor from an external source, usually a steam generator, to maintain desired reactor temperatures.

Under LPO conditions, feed sludge is reacted with approximately 15 SCF[34] air/lb solids (0.94 SCM[35] air/kg solids), while temperatures around 400°F (204°C) and pressures of 400 psig (28 kg/sq cm) are maintained. IPO treatment requires the addition of approximately 45 SCF air/lb solids (2.81 SCM air/kg

TABLE 3.13 TROUBLESHOOTING THERMAL CONDITIONING PROCESSES

Problem	Possible Causes	Check or Monitor	Possible Solution
1. Reactor temperature not maintained	1a. Fuel exhausted b. Temperature sensor and actuators inoperative c. Make-up water supply inadequate	1a. Fuel supply and fuel lines b. Instrumentation c. Water supply	1a. Replenish b. Clean and repair or replace c. Replenish
2. Reactor pressure not maintained	2a. Feed pump inoperative	2a. Grinder, pump suction and discharge valve and sludge supply	2a. Unplug grinder and pump suction. Open suction and discharge valves. Provide thickened sludge.
3. Heat exchanger Δp excessive	3a. Scaling	3a. Inlet and outlet pressures	3a. Acid flush exchangers
4. Reduction in sludge dewaterability	4a. Low temperature b. Low detention time c. Poor operation of decant	4a. Reactor temperature b. Sludge flow c. Thickness of blanket and sludge concentration	4a. Same as 1 b. Thicken feed sludge c. Thicken underflow sludge

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[34] *SCF. Standard cubic feet of air at standard conditions of temperature, pressure and humidity.*

[35] *SCM. Standard cubic meters of air at standard conditions of temperature, pressure and humidity.*

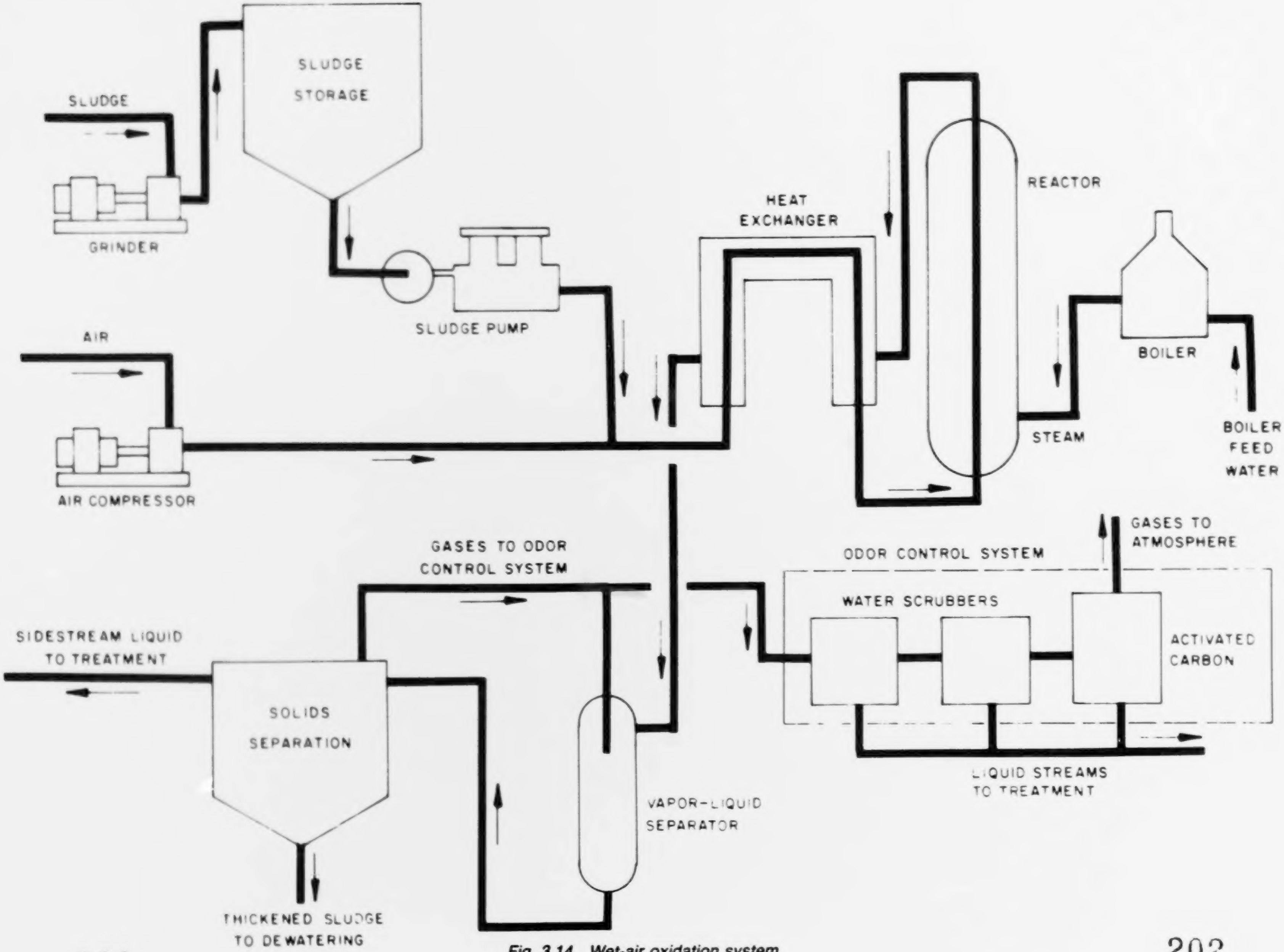
SLUDGE
SLUDGE STORAGE
GRINDER
SLUDGE PUMP
AIR
AIR COMPRESSOR
HEAT EXCHANGER
REACTOR
BOILER
STEAM
BOILER FEED WATER
GASES TO ODOR CONTROL SYSTEM
SIDESTREAM LIQUID TO TREATMENT
SOLIDS SEPARATION
THICKENED SLUDGE TO DEWATERING
VAPOR-LIQUID SEPARATOR
ODOR CONTROL SYSTEM
GASES TO ATMOSPHERE
WATER SCRUBBERS
ACTIVATED CARBON
LIQUID STREAMS TO TREATMENT

Fig. 3.14 Wet-air oxidation system

solids) and reactor temperatures and pressures of 450°F (232°C) and 500 to 600 psig (35 to 42 kg/sq cm), respectively. Under HPO conditions, feed sludge is reacted with approximately 100 SCF air/lb solids (6.24 SCM air/kg solids) while reactor temperatures and pressures approximate 500°F (260°C) and 1,000 to 1,500 psig (70 to 105 kg/sq cm), respectively. For each of the three modes of wet oxidation, reactor detention times usually vary from 20 to 40 minutes.

3.330 Factors Affecting Wet Oxidation

The performance and efficiency of wet oxidation units are dependent on: (1) the concentration and consistency of the feed sludge, (2) reactor detention time, (3) reactor temperature and pressure, and (4) quantity of air supplied.

The effects of feed sludge, reactor temperature and pressure, and reactor detention times are covered in Section 22.32, "Thermal Conditioning." The major difference between wet oxidation and thermal conditioning is that air is introduced for wet oxidation. As wet oxidation progresses from the LPO to HPO mode of operation, the degree of oxidation or conversion of the sludge solids to volatile gases also increases. Thus, an increase in oxidation is due primarily to reacting the sludge with greater quantities of oxygen at elevated temperatures and pressures.

The *OPERATING CRITERIA, NORMAL OPERATING PROCEDURE* and *TROUBLESHOOTING* are the same as those discussed in Section 22.3 (22.321, 22.322, and 22.323) for thermal conditioning except that reactor temperatures and pressures are higher for IPO and HPO. In addition, the quantity of air supplied (SCF per pound of sludge solids) is also higher for IPO and HPO when compared to thermal conditioning.

3.331 Typical Performance

Typical operating guidelines and the degree of oxidation for the three modes of wet oxidation are presented in Table 3.14.

TABLE 3.14 OPERATIONAL AND PERFORMANCE GUIDELINES FOR WET OXIDATION UNITS

	Reactor				% Reduction		
Mode of Operation	°F[a]	PSIG[b]	Detention Time, Min	Air, SCF/lb Solids[c]	Total Solids	VSS	Total COD
LPO	350-400	350- 400	20-60	15	20-25	25-40	25-40
IPO	450	500- 600	20-60	45	30-50	40-60	40-60
HPO	500	1000-1500	20-60	100	70-75	75-85	75-85

[a] (°F − 32°F) × 5/9 = °C
[b] psi × 0.07 = kg/sq cm
[c] SCF/lb × 0.0624 = SCM/kg

In addition to reducing the sludge mass and total COD, wet oxidation should generally result in sterilization (total destruction of pathogenic and nonpathogenic organisms) of the sludge because of the elevated temperatures and the reactor detention times used. The thermally oxidized sludge which is thickened and withdrawn from the bottom of the decant tank usually exhibits excellent dewatering characteristics as will be discussed in Section 3.4, "Dewatering."

One of the drawbacks of wet oxidation or thermal conditioning is the production of noxious odors and high-strength liquid sidestreams. The odors closely resemble that of burned plastic and are produced by volatilizing or converting the organics in the sludge to complex organic gases. The production of odors requires that the off gases from the decant tank be deodorized prior to atmospheric discharge. Therefore, thermal treatment systems must be equipped with gas scrubbers and carbon adsorbers or catalytic combustion units. The operator should become familiar with the operation and maintenance of the air pollution control equipment by reviewing the manufacturer's literature.

The liquid sidestream's (decant tank overflow and dewatering equipment) effluents are extremely high in soluble organics and the operator should be aware that recycling these liquids to the treatment plant headworks may result in operational problems in secondary treatment processes. If problems develop because of the recycling of thermal liquors, separate aerobic or anaerobic treatment may be required.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 255.

3.33A Explain the differences between LPO, IPO, and HPO.

3.33B List the factors affecting wet oxidation.

3.33C Why is air pollution control equipment required on thermal treatment units?

3.34 Elutriation

3.340 Process Description

Elutriation is basically a washing process which may not actually improve the dewatering characteristics of digested sludge, but does reduce chemical conditioning requirements. The reduction in chemical conditioning requirements has been related to a reduction in sludge alkalinity and subsequent reduction in lime requirements for pH adjustment. While dilution of digested sludge with fresh water and/or plant effluent results in a dilution and an apparent reduction in alkalinity, *THE MAJOR REASON FOR IMPROVED DEWATERABILITY IS MOST PROBABLY THE RESULT OF WASHING OUT OF FINE, DIFFICULT TO DEWATER SOLIDS.*

As discussed in Section 3.0, fine, low density solids have large surface areas with possibly high electrostatic charges and are more difficult to dewater than larger and coarser solids. If these fine solids are taken out of the sludge mass, the remaining sludge solids would naturally be easier to dewater. The problem with elutriation is that the fine solids removed from the sludge stream are recycled back to the plant headworks. Sometimes these fine solids may pass through the plant and leave in the plant effluent.

Various case histories testify to the fact that elutriation lowers chemical demands and improves dewaterability, but as much as 50 percent of the digested solids may be lost to the plant effluent with the elutriation effluent (elutriate). The loss of these fine solids into the plant effluent will deteriorate the effluent quality while recycling to the plant headworks generally results in operational problems due to the buildup of fine solids throughout the system.

In general, elutriation is not a preferred or efficient method of sludge conditioning in light of the ever increasing federal, state, and local effluent discharge requirements.

3.341 Operating Guidelines

The simplest and most common method of elutriation is the single-stage method which uses a single contact between the solids and elutriating liquid (elutriate). In this system, the sludge and elutriant make contact in an elutriating tank and are vigorously mixed for 30 to 60 seconds. The mixer is then turned off and the contents allowed to settle from 4 to 24 hours under batch operation, or the contents are delivered to a gravity thickening tank under continuous operation. After the sludge and elutriant are vigorously mixed and settled or delivered to a gravity thickener, the operation becomes one of gravity thickening and the reader should refer to Section 3.1 for operating strategies.

QUESTION

Write your answers in a notebook and then compare your answers with those on page 255.

3.34A How does elutriation improve the dewaterability of sludge? Discuss the problems associated with the process.

END OF LESSON 3
OF 5 LESSONS
ON
SLUDGE HANDLING
AND
DISPOSAL

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 3 of 5 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 2.

13. How is the optimum type of chemical and dose to condition a particular sludge determined? Why?
14. What are the most common problems encountered with automatic dry chemical feed systems? List the cause of each problem.
15. How would you attempt to identify the cause of a decrease in the performance of sludge thickening or dewatering processes when the problems appear to be with the chemical conditioning facilities?
16. List the types of problems typically encountered on a day-to-day basis with a thermal conditioning system.
17. How are odors controlled from thermal treatment systems?

CHAPTER 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 4 of 5 Lessons)

3.4 DEWATERING

3.40 Purpose of Dewatering

Following stabilization, wastewater sludges can be ultimately disposed of by a variety of methods or they can be dewatered prior to further processing and/or ultimate disposal. In general, it is more economical to dewater sludge followed by disposal than it is to pump or haul liquid sludge to disposal sites. The primary objective of dewatering is to reduce sludge moisture and consequently sludge volume to a degree that will allow for economical disposal. Unit processes most often used for dewatering are: (1) pressure filtration, (2) vacuum filtration, (3) centrifugation, and (4) sand drying beds.

3.41 Pressure Filtration

Basically, there are two types of pressure filtration systems used for sludge dewatering. These are: (1) plate and frame filter press, and (2) belt filter press. The operating mechanics of these two filter press types are totally different and each will be discussed.

3.410 Plate and Frame Filter Press

The plate and frame filter press operates in a batch manner and consists of vertical plates which are held rigidly in a frame and pressed together. A schematic diagram of a typical plate section is shown in Figure 3.15. Sludge is fed into the press through feed holes along the length of the press. A filter cloth is mounted on the face of each individual plate. As filtration proceeds, water (filtrate) passes through the fibers of the cloth, is collected in drainage ports provided at the bottom of each press chamber and is discharged. Sludge solids are retained on the filter cloths and are allowed to build up until the cavities between the plates are completely filled with solids (cake). As the cake builds up between the plates, the resistance to flow increases because the water has to pass through a thicker layer of compacted solids. As the cake builds up and the resistance increases, the volume of sludge fed to the filter and consequently the volume of filtrate decreases. When the filtrate flow is near zero, the feed is shut off and the plates are disengaged. As the plates are pulled away from each other, the retained cakes are discharged by gravity and fall into a hopper or conveyor. The diaphragm press or variable volume type filter presses have expandable membranes on the plate faces to further dewater the cake and to ease cake removal. After the cakes are discharged, the plates are pulled back together and the feed restarted.

3.4100 Factors Affecting Pressure Filtration Performance. The degree of dewatering and sludge solids removal efficiency are affected by: (1) sludge type, (2) conditioning, (3) filter pressure, (4) filtration time, (5) solids loadings, (6) filter cloth type, and (7) *PRECOAT*[36].

Both the sludge type and conditioning methods used will drastically affect the operation and performance of filter presses. *PRIMARY SLUDGES DEWATER MORE READILY AND REQUIRE LESS CHEMICAL CONDITIONERS THAN SECONDARY SLUDGES.* Chemicals used to condition sludge prior to plate and frame filtration generally are lime or ferric chloride. As the quantity of chemical conditioners increases, the dryness of the discharged cake solids and the sludge solids removal also increase. As discussed in Section 3.3, the optimum chemical dosages are determined by jar-test experiments followed by pilot or full-scale tests. Experience has shown that various combinations of lime, ferric chloride, ash and/or polymer can be used to condition sludge prior to plate and frame filtration. If the chemical dosages are less than optimum, the performance of the filter press also will be less than optimum. Thermal conditioning or wet oxidation of wastewater sludges followed by gravity thickening yields a readily dewaterable sludge. The operating criteria maintained in the thermal conditioning system will have definite effects on sludge dewaterability. As discussed in Section 3.32, the thermal conditioning system should be operated so as to obtain the desired degree of dewatering by pressure filtration. The operating criteria and their effects on filter performance are discussed below.

3.4101 Operating Guidelines. The operator has the ability to control filter press performance to a certain degree by controlling the pressure, time of filtration and the solids loading. Selection of a particular type of filter cloth for a specific sludge is generally done by pilot or full-scale testing with various cloth types. Once a filter cloth is selected and installed, the operator must control the frequency and duration of media cleaning.

PRESSURE

The feed to filter presses is initiated at low pressure and high flow rates. As the cake builds up and the resistance to flow increases, a pneumatically or hydraulically driven positive displacement feed pump provides increasing pressure as the flow drops off. Generally, the initial pressure is maintained at approximately 25 psi (1.75 kg/sq cm) for 5 to 10 minutes then increased at intervals approximating 5 psi/min (0.35 kg/sq cm/min) until the terminal operating pressure is reached. Final operating pressures usually vary from 100 to 225 psi (7.0 to 15.8 kg/sq cm) depending on the manufacturer of the press. Some presses are designed to operate at 100 to 125 psi (7.0 to 8.8 kg/sq cm). In general, higher pressures should result in somewhat drier discharge by forcing more water from the sludge mass. The most effective pressure for a particular sludge is determined by experimentation and the operator

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[36] *Precoat. Application of a free-draining, noncohesive material such as diatomaceous earth to a filtering media. Precoating reduces the frequency of media washing and facilitates cake discharge.*

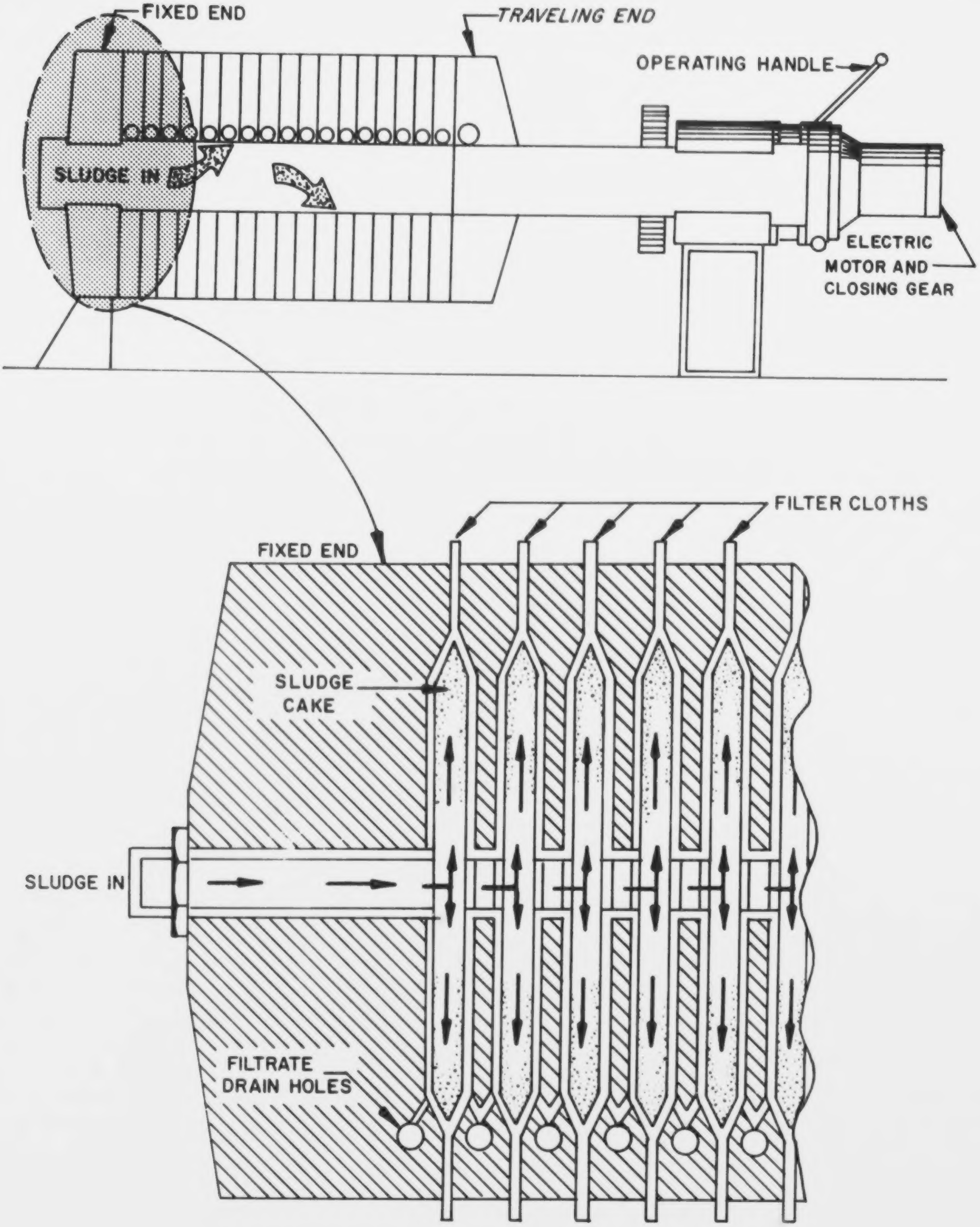
FIXED END
TRAVELING END
OPERATING HANDLE
SLUDGE IN
ELECTRIC MOTOR AND CLOSING GEAR
FILTER CLOTHS
FIXED END
SLUDGE CAKE
SLUDGE IN
FILTRATE DRAIN HOLES

Fig. 3.15 Plate and frame filter press

should be aware that increased cake dryness may result from increased operating pressures. For some sludges, particularly secondary sludge, the reverse might happen. That is, as the pressure is increased, the sludge retained on the filtering media may compress to a higher degree and reduce the porosity (openings) of the sludge cake that is formed. If the openings in the sludge formation are reduced, fine low-density solids may be captured and incorporated in the sludge cake. The inclusion of fine solids generally results in wetter cakes because these solids have large surface areas and relatively large quantities of water associated with them.

FILTRATION TIME AND SOLIDS LOADING

The time of filtration is actually controlled by the physical size of the filter and solids loading rate applied. As discussed, when the cavities between the plates are filled with solids and the filtrate flow is almost zero, the filtering sequence is complete. Obviously, for a given cavity volume, the filtration time will vary as the solids loading rate and the dewaterability vary. If the time of filtration is not adequate to completely fill the plate cavities with dewatered solids, large volumes of water will be discharged when the plates are disengaged and the cakes discharged. The operator should control filtration time based on the filtrate flow rate. If on the other hand, the filtration time exceeds the time required to fill the cavity volume, the cakes will be firm and dry upon discharge but the quantity of solids processed per hour or per day (solids loading) will decrease.

The solids loading is determined by dividing the pounds of solids applied per hour by the surface area of the plates. Since filter presses are batch systems, time is lost in disengaging the plates, discharging the cakes and re-engaging the plates prior to restarting the feed pump. The incorporation of down time into the solids loading equation results in a net filter yield. The following example illustrates the determination of solids loading and net filter yield.

EXAMPLE 35

Given: A particular filter press with a plate surface area of 100 sq ft is used to dewater digested primary sludge. The digested sludge is at a concentration of 3.0 percent sludge solids. The filtration time is 2 hours and the total volume of sludge processed is 700 gallons. The time required to discharge the cakes and restart the feed is 20 minutes.

Find:
1. The solids loading (lbs/hr/sq ft).
2. The net filter yield (lbs/hr/sq ft).
3. If the feed solids concentration decreased to 2 percent sludge solids and the filtration time remained at 2 hours, what problems might develop?

Solution:

Known		**Unknown**
Plate Area, sq ft	= 100 sq ft	1. Solids Loading, lbs/hr/sq ft
Sl Sol, %	= 3.0%	2. Net Filter Yield, lbs/hr/sq ft
Filtration Time, hrs	= 2 hrs	3. If solids drop to 2% Sl Sol, what problems might develop?
Sludge Volume, gal	= 700 gal	
Discharge and Restart, min	= 20 min	

1. Calculate the solids loading in pounds per hour per square foot.

$$\text{Solids Loading, lbs/hr/sq ft} = \frac{\text{Sl Vol, gal} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}}{\text{Filt. Time, hr} \times \text{Area, sq ft}}$$

$$= \frac{700\text{ gal} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{3.0\%}{100\%}}{2\text{ hr} \times 100\text{ sq ft}}$$

$$= 0.88\text{ lbs/hr/sq ft}$$

2. Calculate net filter yield in pounds per hour per square foot.

$$\text{Net Filter Yield, lbs/hr/sq ft} = \frac{\text{Loading, } \frac{\text{lbs/hr}}{\text{sq ft}} \times \text{Filt Time, min}}{\text{Filt Time, min} + \text{Down Time, min}}$$

$$= \frac{0.88\text{ lbs/hr/sq ft} \times 120\text{ min}}{120\text{ min} + 20\text{ min}}$$

$$= 0.75\text{ lbs/hr/sq ft}$$

3. What would happen if the feed concentration decreased to 2 percent sludge solids?

If the feed solids concentration decreases to 2 percent sludge solids, the cake *MAY* be wetter upon discharge if the filtration time is not increased. The operator should check the filtrate flow and adjust the filtration time so that the filtrate flow is near zero when the feed pump is turned off.

FILTER CLOTH AND PRECOAT

The selection of a particular cloth type is done by experimentation in conjunction with the manufacturer's recommendation. Once a cloth is selected and installed, the operator must determine the frequency of media cleaning by inspecting the condition of the cloth and monitoring filter performance. After repeated use, the cloth media may *BLIND*[37] and adversely affect filter performance. If the cloth is clogged, water will not drain as readily and the discharged cakes will be wet and sloppy upon release from the plates. Also, as the cloth becomes clogged, a longer time will be required to dry the cake. Some presses are furnished with media washing equipment and the media can be cleaned in place. If a washing system is not furnished with the press, the operator will have to remove the filter cloths, wash them according to the manufacturer's recommended procedure, then re-install them. To reduce the frequency of media washing and to facilitate cake discharge, a precoat may be applied before each batch is loaded for filtering. Precoating is an optimal operation and uses a free-draining, non-cohesive material such as diatomaceous earth (a fine siliceous earth consisting mainly of the skeletal remains of diatoms). This is made into a slurry and is applied to the filter so as to leave a thin layer on the filter cloth. When the sludge is applied, the precoat material prevents the sludge solids from sticking to the filter cloth. The net effect is that when the filter press is opened, the cake will readily discharge and solids remaining on the cloth will be minimized. The operator can improve operation and performance of filter presses by using precoats; however, precoating adds to the solids load to be disposed of.

3.4102 Normal Operating Procedure. The specific operation of different pressure filters will vary somewhat, but the basic operational procedures are similar. The filtration cycle can be divided into various steps: (1) preparation of precoat and chemical conditioners, (2) chemical conditioner and sludge mixing, (3) precoat application, (4) sludge application, and (5) cake discharge.

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[37] *Blind. A condition that occurs on the filtering medium of a microscreen or a vacuum filter when the holes or spaces in the media become clogged or sealed off due to a buildup of grease or the material being filtered.*

The procedures for normal operation are outlined below:

1. Slurry (add water to) the precoat mix in a separate precoat tank.
2. Slurry the lime, if used, in a separate lime slurry tank.
3. Transfer the lime to a separate tank containing the sludge to be filtered and provide gentle stirring. Add the appropriate quantity of ferric chloride, if used. Usually either lime or ferric chloride is used as a chemical conditioner.
4. Apply the precoat material to the filter.
5. Introduce the conditioned sludge to the filter.
6. When the filtrate flow decreases to near zero, turn off the feed pump.
7. Disengage and open the press for cake discharge.
8. Close the press and repeat the above procedures.

Full-scale filter press installations are generally automated or semi-automated so as to reduce operator attention. Even with fully automated systems, the operator should routinely check the operation of the various equipment and should make adjustments as required.

3.4103 Typical Performance. Operating guidelines, conditioner requirements, and filter press performance for various sludge types are summarized in Table 3.15. Note that when thermal conditioning is used, precoat material and chemical conditioners are often not required.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 255.

3.40A What are the primary objectives of sludge dewatering?

3.40B What unit processes are most commonly used for sludge dewatering?

3.41A Why does the flow through plate and frame filter presses decrease with filtration time?

3.41B List the factors that affect pressure filtration performance.

3.41C Increasing the operating pressure might result in wetter cakes. Why?

3.41D How should the time of filtration be controlled?

3.41E What purpose does precoating serve?

3.41F List the NORMAL operation procedures for filter presses.

3.41G The typical performance data presented in Table 3.15 indicates that secondary sludges do not dewater as readily as primary sludges. Why is this so?

3.4104 Troubleshooting. The operator should be concerned with the characteristics of the cakes discharged at the end of the filtration cycle. Generaly, filter presses consistently produce excellent effluents (filtrate) unless the filtering media is torn or not properly installed. Routine monotoring of both the filtrate and cake is required for continued successful operation.

Depending on the operation and performance of filter presses, the discharge cakes will be: (1) firm and dry throughout, (2) firm and dry at the outer sections with wet and sloppy inner sections, or (3) wet and sloppy throughout.

A firm and dry cake indicates good filter press operation and no adjustments are necessary. If the cakes are firm and dry at the ends but are composed of liquid centers, the operator should check filtration time and chemical dosages. The filtration time should be checked by monitoring the filtrate flow on a subsequent filter run. If the filtration time is not adequate, the cavities between the plates will not fill completely with solids and the innermost portions of the cakes will be wet. The operator should increase the filtration time so as to obtain near zero filtration flow at the end of the feed cycle. If the cakes are wet throughout, either the filtration time should be increased if necessary or the pressure should be monitored during a subsequent run. If the desired pressure is not being developed, the operator should check the condition and operation of the high-pressure feed pump and the condition and installation of the filter cloths. A tear in the filtering media or misalignment of the cloths will cause a lot of the sludge to pass through the filter without building up between the plates, and will usually result in poor effluent quality. The operator also should check to determine if the poor effluent quality is related to a clogged or dirty filter cloth. If the pressure is as desired and the filtrate quality is good, inconsistent and wet cakes could develop from a low chemical dosage. The operator should check all aspects of the chemical conditioning system and adjust the chemical dosage to achieve the desired degree of dewatering.

If precoats are used to aid in discharge of the dewatered solids, the operator should check the precoat system if relatively large quantities of solids remain on the filter cloths upon discharge.

Table 3.16 summarizes potential operational problems and corrective measures to assist in maintaining effective filter press dewatering.

TABLE 3.15 TYPICAL PERFORMANCE OF PLATE AND FRAME FILTER PRESS

	Chemical Conditioners							
Sludge Type	Lime (lb/ton)[a]	or	$FeCl_3$ (lb/ton)[a]	Thermal Treat.	Pressure, psig[b]	Yield, lbs/hr/sq ft[c]	Cake Solids, % TS[d]	Solids Recovery, %
Primary	100 - 200		100 - 200	—	100-200	0.5 - 1.0	40-50	90 - 99
Primary	—		—	LPO	100-200	0.5 - 1.2	40-50	90 - 99
Secondary	200 - 500		100 - 400	—	100-200	0.1 - 0.3	20-30	90 - 99
Secondary	—		—	LPO	100-200	0.1 - 0.4	20-40	90 - 99
Dig. Primary	100 - 400		100 - 200	—	100-200	0.5 - 1.0	40-50	90 - 99
Dig. Primary	—		—	LPO	100-200	0.5 - 1.0	40-50	90 - 99
Dig. Primary	200 - 600		100 - 400	—	100-200	0.1 - 0.3	20-30	90 - 99
Dig. Secondary	200 - 600		100 - 400	—	100-200	0.1 - 0.3	20-30	90 - 99
Dig. Secondary	—		—	LPO	100-200	0.1 - 0.4	20-30	90 - 99

[a] lb chemical/ton dry solids. lbs/ton × 0.5 = gm chemical/kg dry solids

[b] psi × 0.07 = kg/hr/sq m

[c] lbs/hr/sq ft × 4.883 = kg/hr/sq m

[d] Thickened sludge

TABLE 3.16 TROUBLESHOOTING PLATE AND FRAME FILTER PRESSES

Operational Problem	Possible Causes	Check or Monitor	Possible Solutions
1. Inner portions of cakes wet and sloppy upon discharge	1a. Low filtration time	1a. Filtrate flow for an entire run	1a. Increase filtration time
	b. Low pressure	b. Pressure developed	b. Repair and/or unplug feed pump. Align filter media
	c. Chemical inefficiencies	c. Chemical dosages	c. Increase chemical dosage
2. Cakes wet throughout	2a. Low filtration time	2a. Filtration flow	2a. Increase filtration time
	b. Low pressure	b. Pressure developed. Check media for tears or misalignment	b. Repair feed pump. Replace and/or realign media
	c. Chemical inefficiencies	c. Chemical equipment and dosage	c. Increase chemical dosage
3. Solids remain on cloth upon discharge	3a. Precoat inefficiencies	3a. Precoat application and dosage	3a. Increase precoat dosage

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 255.

3.41H What measures should be taken if the discharge cakes from a filter press are wet throughout?

3.41I Why do solids occasionally cling to the filtering media when the cakes are discharged?

3.411 Belt Filter Press

Belt filter presses operate in a continuous manner and consist of two endless belts that travel over a series of rollers. Variations in belt fiter designs are available from different manufacturers, but the basic principles are the same for all belt filters. A schematic of a typical belt filter press is presented in Figure 3.16. Sludge to be dewatered is pre-conditioned, usually with polymers, then applied to the free-water drainage zone of the filter belt. This portion of the belt is so named because it allows for most of the free water to drain through the filter and to be collected in a trough on the underside of the belt. The main differences between different brandname filter types are the method of introducing and mixing chemicals with the sludge and the type of drainage zone used. Some presses use in-line polymer mixing where the polymer is added directly to the feed line and mixed with sludge by passing the flow through a Venturi-type restriction to create mild turbulence. With this type of chemical mixing system, the conditioned sludge is applied to a horizontal "drainage zone" as shown in Figure 3.16.

Mixing chambers also can be used to ensure adequate polymer and sludge contact. Such chambers are cylindrical in design and slowly rotate to allow the polymer to mix with the sludge. Mixing chambers simply replace the Venturi-type restriction for creating mild turbulence. When the conditioned sludge moves out of the mix chamber, it can be applied directly to a horizontal drainage zone as discussed above or it can be delivered to a cylindrical "reactor chamber." The reactor chamber replaces the horizontal drainage zone and consists of a screen around the outside edge of the chamber which allows most of the free water to drain out.

Regardless of the polymer mixing and "drainage zone" dewatering used, the partially dewatered solids are carried to a point on the unit where they are trapped between two endless belts and further dewatered as they travel over a series of perforated and unperforated rollers. This zone is known as the "press" or "dewatering zone." In this zone, the entrapped solids are subjected to shearing forces as they proceed over the rollers. Water is forced from between the belts and collected in filtrate trays while the retained solids are scraped from the two belts when they separate at the discharge end of the press. The two endless belts then travel through respective washing chambers for the removal of fine solids to decrease the possibility of plugging.

3.4110 Factors Affecting Belt Pressure Filtration. The ability of belt filter pressues to dewater sludge and to remove suspended solids is dependent on: (1) sludge type, (2) conditioning, (3) belt tension or pressure, (4) belt speed, (5) hydraulic loading, and (6) belt type.

Sludge type, consistency of the feed, and chemical conditioning will affect the performance of belt filters. Polymers are generally used for chemical conditioning in conjunction with belt filter operations. Polymer dosages must be optimized to ensure optimum dewatering. Unlike plate and frame filter presses which can consistently handle secondary sludge if properly conditioned with chemicals, the belt filter might not be able to handle secondary or waste activated sludges consistently. Even with adequate polymer addition to flocculate and to cause a separation of solids from the liquid, the belt press might not be suitable for dewatering secondary sludges. Secondary sludges generally lack fibrous materials and exhibit a plastic or jello-like nature. When these sludges are trapped between the two belts and pressure is applied by the rollers, they tend to slip towards the belt sides and eventually squeeze out from between the belts. The net effects are that these solids contaminate the effluent by falling into the filtrate trays and continued housekeeping is required. If this problem is evident, primary sludge may have to be blended with the secondary sludge to add fibrous material necessary to contain the sludge between the belts. This procedure has produced sludge cakes in the range of 24 to 26 percent solids with the use of polymers.

The operating guidelines available to vary the degree of dewatering are discussed below.

3.4111 Operating Guidelines. A well-operated belt filter press should result in a high degree of dewatering provided the operator is aware of the important operating controls.

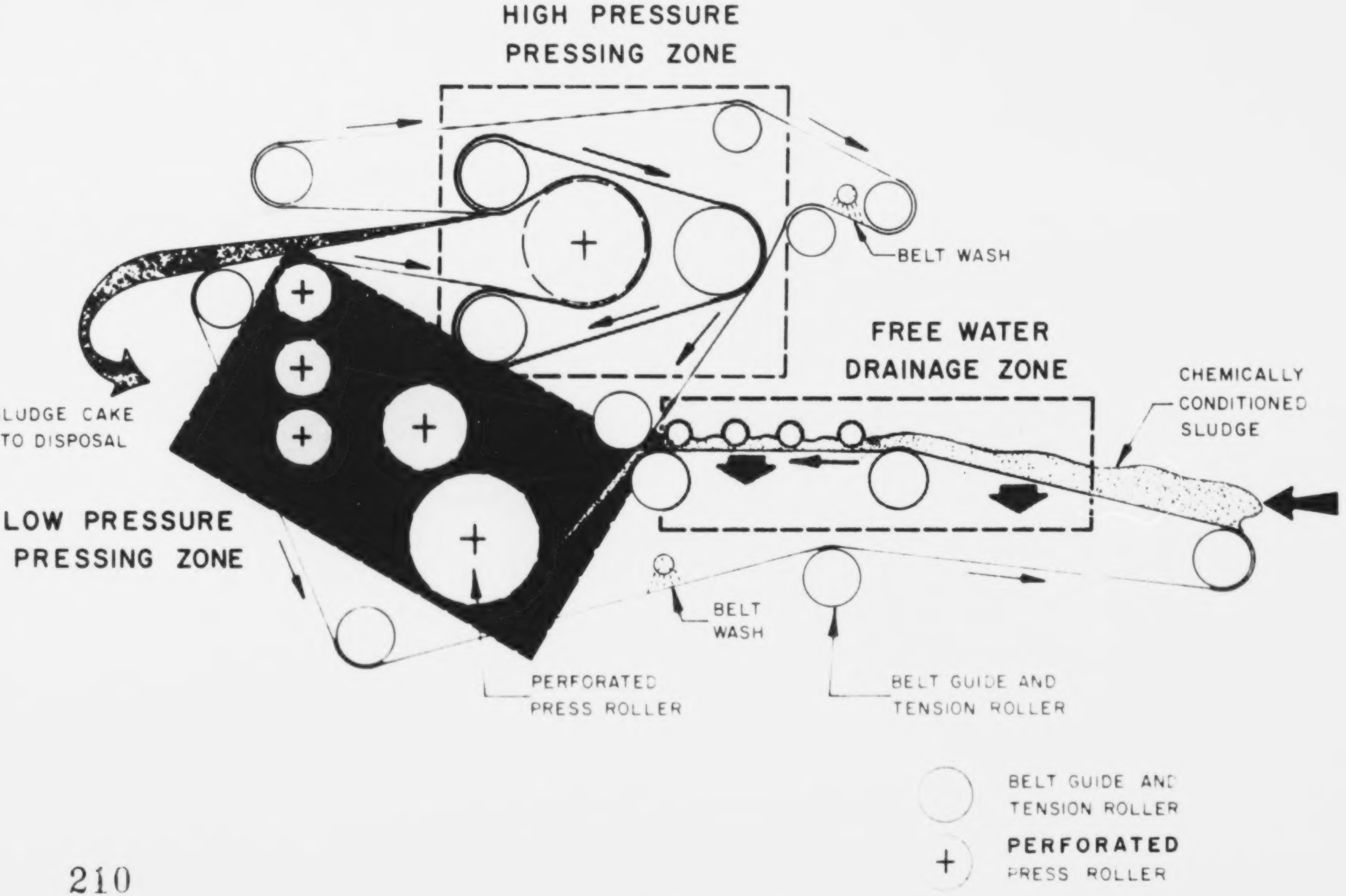
HIGH PRESSURE PRESSING ZONE
BELT WASH
FREE WATER DRAINAGE ZONE
CHEMICALLY CONDITIONED SLUDGE
SLUDGE CAKE TO DISPOSAL
LOW PRESSURE PRESSING ZONE
BELT WASH
PERFORATED PRESS ROLLER
BELT GUIDE AND TENSION ROLLER
BELT GUIDE AND TENSION ROLLER
PERFORATED PRESS ROLLER

Fig. 3.16 Belt filter press

BELT TENSION PRESSURE

The operator can increase or decrease the pressure applied to the sludge by adjusting the tension rollers to take up slack on the two endless belts. As the belt tension is increased, more water is generally squeezed from the belt resulting in drier cakes. The pressure variations available on each manufacturer's belt press are different and the operator should consult the manufacturer's literature to determine the range of operating pressures. Although pressure increases usually result in drier cakes, some undesirable conditions may develop as a result of increasing the tension between the belts. These are: (1) sludge may be forced from between the belts due to increased shear forces, or (2) sludge may be forced through the belt. Both of these conditions will result in filtrate contamination and increased housekeeping requirements. The optimum operating pressure should be selected by the operator so as to produce the driest cake possible while containing the sludge between the belts.

BELT SPEED AND HYDRAULIC LOADING

The belt speed can be varied from approximately 2 to 10 feet/minute (0.6 to 3 m/min). The speed at which the belt should be operated depends on the sludge flow rate to the belt and the concentration of the influent sludge. Since most of the water associated with the sludge is removed in the drainage zone, sufficient belt area has to be provided to allow the water to drain. As the belt speed is increased, the rate of belt area contacting the influent sludge also increases and allows for greater volumes of water to drain from the sludge. If the belt area is not sufficient enough to allow the free water to drain, a "washing out" of the belt will occur. Washing out means that large quantities of free water unable to be released in the drainage zone will travel to the dewatering zone and flow out from between the belts and drastically reduce effluent quality.

The belt speed should be controlled so that the sludge delivered to the dewatering zone has a minimum amount of free water. The experienced operator will be able to optimize belt speed by observing the dryness of the solids delivered to the dewatering zone. Obviously, as the concentration of influent sludge increases, less water is associated with the sludge mass and reduced belt speeds can be used. *THE IDEAL OPERATING BELT SPEED IS THE SLOWEST THE OPERATOR CAN MAINTAIN WITHOUT "WASHING OUT" THE BELT.* As the belt speed decreases, cake dryness increases because the sludge is subjected to pressure and shearing forces for longer periods of time.

Hydraulic loadings are based on the flow rate applied per unit of belt width. Belt presses range in width from approximately 1.5 feet to 7.0 feet (0.45 to 2.1 m). Manufacturers generally recommend loadings of 10 to 25 GPM per foot (180 to 450 cu m/day/m) of belt width. The ideal loading for a particular belt press and a specific sludge should be determined on the basis of dewatering performance and consistency of operation. If a belt press is operated close to the upper hydraulic limit, frequent "washing out" may result due to slight variations in sludge characteristics and/or chemical dosages. An example for the calculation of the hydraulic loading follows.

EXAMPLE 36

Given: A 6-foot-wide belt press receives 100 GPM of primary sludge at a concentration of 5 percent.

Find: The hydraulic loading, GPM/ft

Solution:

Known		**Unknown**
Belt Filter Press		Hydraulic Loading, GPM/ft
Belt Width, ft	= 6 ft	
Flow, GPM	= 100 GPM	
SI Sol, %	= 5%	

Determine the hydraulic loading in gallons per minute per foot.

$$\text{Hydraulic Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Belt Width, ft}}$$

$$= \frac{100\ \text{GPM}}{6\ \text{ft}}$$

$$= 16.7\ \text{GPM/ft}$$

BELT TYPE

Belts are available in a variety of materials (nylon, polypropylene), each with various porosities. Porosity is a measure of fiber openings. As the porosity increases, the resistance to flow decreases and larger volumes of water are able to be drained. If the porosity (fiber openings) is too large, sludge solids may pass through the belt and result in poor filtrate quality. If the porosity is too low, the belt may blind or plug which will produce frequent "washouts." The right belt for a particular application is determined by experimentation in conjunction with manufacturer's recommendations. After a belt is selected and installed, the operator should provide for adequate belt cleaning by maintaining the belt-washing equipment in proper working condition and by adjusting the washwater volume as required.

3.4412 Normal Operating Procedure. The operation of different belt filters will vary somewhat, but the following procedures will be applicable for most cases:

1. Prepare an adequate supply of an appropriate polymer solution.
2. Turn on the washwater sprays and the belt drive.
3. Adjust the belt speed to its maximum setting and allow the washwater to wet the entire belt.
4. Turn on the mix drum and reactor drum if applicable.
5. Open appropriate sludge and polymer valves.
6. Turn on the polymer pump and adjust the polymer rate as required to achieve the desired dosage.
7. Turn on the sludge feed pump.
8. Lower the belt speed as low as possible without running the risk of "washing out."
9. Adjust the belt tension as required.
10. Turn on the dewatered sludge conveyor.

The operator should routinely check the operation of the belt press and make adjustments as required to produce a dry cake and good filtrate quality.

3.4113 Typical Performance. Operating guidelines, polymer requirements, and typical performance data are presented in Table 3.17.

TABLE 3.17 TYPICAL PERFORMANCE OF BELT PRESS FILTRATION UNITS

Sludge Type	Polymer, lbs/ton[a]	Cake, % TS[b]	SS Recovery, %	Hyd. Load, GPM/ft[c]
Primary	4 - 8	25-35	95 - 99	10 - 25
Secondary	9 - 20	17-20	90 - 99	5 - 15
Dig. Primary	4 - 8	25-30	95 - 99	10 - 25
Dig. Secondary	15 - 30	17-20	90 - 99	5 - 15

[a] lb of dry polymer/ton dry sludge solids. lbs/ton × 0.5 = gm polymer/kg dry sludge solids
[b] Thickened sludge
[c] GPM/ft × 0.207 = *L*/sec/m

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 256.

3.41J What purpose does the drainage zone serve?

3.41K What is the function of mix chambers used on some belt presses?

3.41L What is the purpose of reactor chambers used on some belt presses?

3.41M Describe the function of the "press" or "dewatering zone."

3.41N List the factors affecting belt filter performance.

3.41O What problems might be expected when using a belt press to dewater secondary sludge?

3.41P How does pressure affect belt press operation?

3.41Q Explain how low belt speed affects belt press performance.

3.41R What does the term "washing out" mean?

3.41S What is the ideal belt speed?

3.41T How does belt type affect belt press performance and what problem may develop if the porosity is too low?

3.4114 Troubleshooting. A close watch over belt press operation in combination with field experience should enable the operator to optimize performance. In addition to mechanical reliability and maintenance, the operator should be concerned with the filtrate quality and dryness of the dewatered sludge. The most frequent problem encountered with belt presses is "washing out." Usually this problem is indicated by large volumes of water carrying onto the dewatering zone and overrunning the sides of the belt. When this happens the operator should check: (1) the polymer dosage, (2) adequate mixing in reactor, (3) hydraulic loading, (4) drum speed, (5) belt speed, and (6) belt washing equipment.

If the polymer dosage is too low, the solids will not flocculate and free water will not be released from the sludge mass. If the polymer dosage is adequate as evidenced by large floc particles and free water, the operator should increase the belt speed so as to provide more belt surface area for drainage. If the belt is already at its maximum setting, the operator should check the flow rate to the press and reduce it if the rate is higher than normal. If the polymer dosage, belt speed, and hydraulic loading are set properly but "washing out" still persists, the problem may be related to blinding of the filter media. The operator should check the appearance of the belts as they leave their respective washing chambers. If the belts appear to be dirtier than normal, the operator should increase the washwater rate and turn off the polymer and feed pumps and allow the belts to be washed until they are clean. Belt blinding often develops because of polymer overdosing. If too much polymer is added, the belts can become coated with a film of excess chemical which will prevent drainage and result in "washing out" of the belt. The operator should check the polymer addition rate and adjust the rate as required so as not to grossly overdose the sludge.

Poor effluent quality will generally result from "washing out" or from sludge being forced either through or from the sides of the belt. If sludge is forced from the belts, the operator should check the belt tension and condition of the belts. Again, if the belts are dirty and water is prevented from draining, the sludge and water will squeeze from the belt side when they are subjected to pressure in the dewatering zone. The operator can reduce belt tension somewhat and clean the belts to eliminate the problem.

If the unit is working as expected, that is the sludge is contained between the belts and filtrate quality is good but the discharge cakes are not as dry as desired, the operator can reduce the belt speed and/or increase the tension somewhat to achieve drier cakes. After a change in belt speed is made, the operator should observe the operation for at least 15 minutes to make certain that a "wash out" will not occur.

Table 3.18 summarizes typical operational problems and corrective measures that could be taken to optimize belt press performance.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 256.

3.41U What steps should the operator take if "washing out" of the belt develops.

3.41V How can blinding of the belt be corrected?

3.412 Vacuum Filtration

A vacuum filter consists of a rotating drum which continuously passes through a trough or pan containing the sludge to be dewatered. A typical rotary-drum vacuum filter is shown in Figures 3.17 and 3.18, with an operation schematic in Figure 3.19. The cylindrical drum, which is covered with some type of cloth media is submerged about 20 to 40 percent in the trough. The trough is usually equipped with an agitator to keep the chemically conditioned sludge well mixed and to keep sludge from settling in the trough. The filter drum is divided into compartments. In sequence, each compartment is subject to vacuums ranging from 15 to 30 inches (38 to 75 cm) of mercury. As the vacuum is applied to the compartment of the drum submerged in the trough, sludge is picked up on the filter media and a sludge mat is formed. This is known as the "mat formation" or "sludge pick-up zone." As the drum rotates out of the trough, the vacuum is decreased slightly and water is sucked from the sludge mat, through the filter media and discharged through internal pipes to a drainage system. This is known as the "drying zone" of the cycle. Just prior to the point where the media separates from the drum, the vacuum is reduced to zero. The dewatered solids remaining on the filter media are then discharged to a sludge hopper or conveyor via scrapers or discharge rollers. The cloth then regulates with the drum and is reintroduced into the sludge trough for another cycle.

3.4120 Factors Affecting Vacuum Filtration. The following factors can have pronounced effects on the operation and performance of vacuum filters: (1) sludge type, (2) conditioning, (3) applied vacuum, (4) drum speed or cycle time, (5) depth of submergence, and (6) media type and condition.

The sludge type and the conditioning methods used will drastically affect filter operation. In general, *STRAIGHT (ONLY) SECONDARY SLUDGES (DIGESTED OR UNDIGESTED) ARE NOT EASILY DEWATERED BY VACUUM FILTRATION* because they do not dewater enough to readily discharge from the belt; however, *THERMALLY CONDITIONED* secondary sludges can be effectively dewatered with a vacuum filter. Even with extremely high dosages of lime and ferric chloride, secondary sludges that have not been thermally conditioned will generally not dewater effectively. Such sludges usually require blending with primary sludges prior to vacuum filtration for successful dewatering.

TABLE 3.18 TROUBLESHOOTING BELT FILTER PRESS

Operational Problem	Possible Cause	Check or Monitor	Possible Solution
1. Washing out of belt	1a. Polymer dosage insufficient	1b. Polymer flow rate and solution	1a. Increase dose rate
	b. Hydraulic load too high	b. Sludge flow rate	b. Lower flow
	c. Belt speed too low	c. Belt speed	c. Increase speed
	d. Belt blinding	d. Washing equipment and polymer overdosage	d. Increase washwater rate. Turn off sludge and polymer and clean belts. Reduce polymer if overdosing
2. Poor filtrate quality.	2a. Washing out	2a. Same as 1	2a. Same as 1
	b. Sludge squeezed from belt	b. Belt tension Washing equipment	b. Decrease tension. Wash the belt
3. Cake solids too wet.	3a. Belt speed too high	3a. Belt speed	3a. Reduce belt speed
	b. Belt tension too low	b. Belt tension	b. Increase belt tension

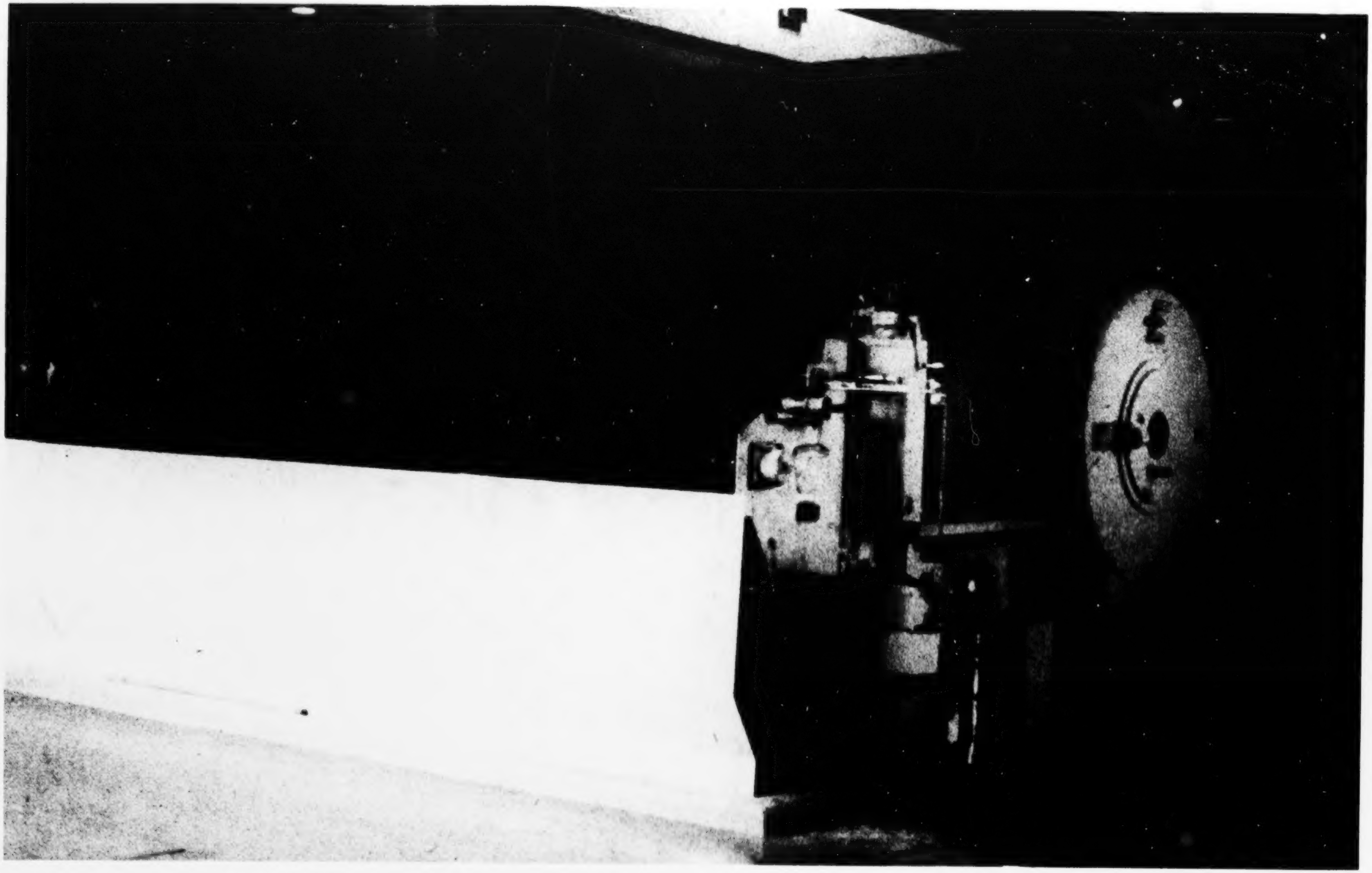

Fig. 3.17 Vacuum filter
(Permission of Eimco)

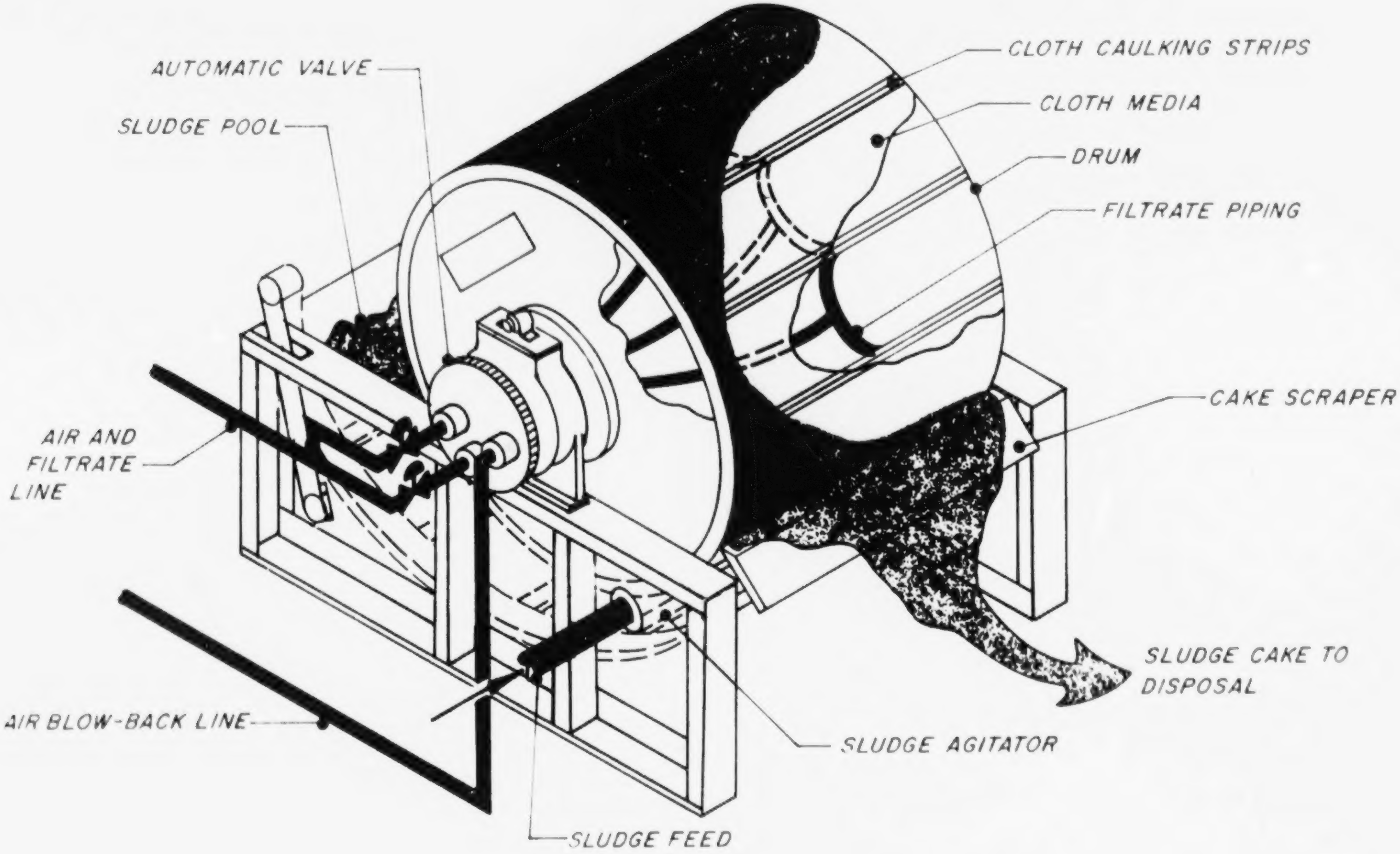
AUTOMATIC VALVE
SLUDGE POOL
CLOTH CAULKING STRIPS
CLOTH MEDIA
DRUM
FILTRATE PIPING
CAKE SCRAPER
AIR AND FILTRATE LINE
SLUDGE CAKE TO DISPOSAL
SLUDGE AGITATOR
AIR BLOW-BACK LINE
SLUDGE FEED

Fig. 3.18 Rotary drum vacuum filter

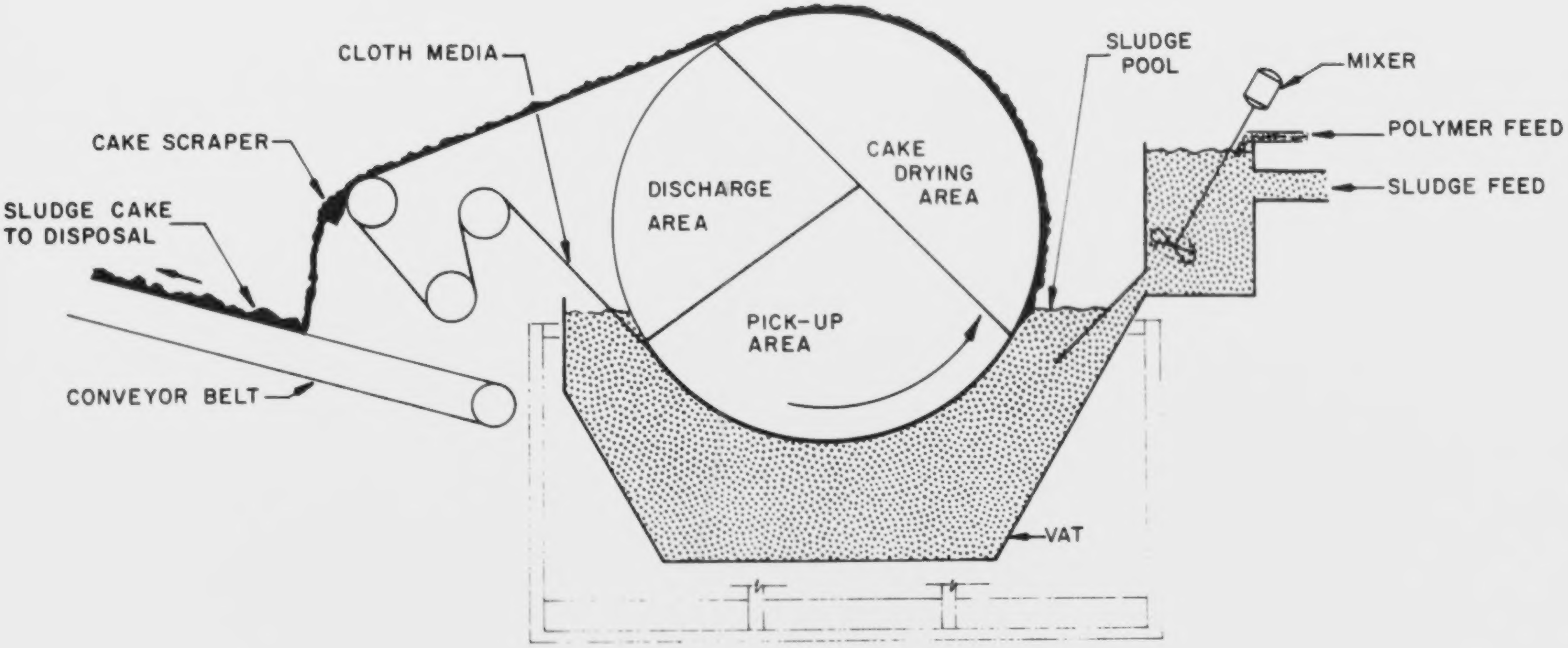
CLOTH MEDIA
CAKE SCRAPER
SLUDGE CAKE TO DISPOSAL
CONVEYOR BELT
DISCHARGE AREA
CAKE DRYING AREA
PICK-UP AREA
SLUDGE POOL
MIXER
POLYMER FEED
SLUDGE FEED
VAT

Fig. 3.19 Vacuum filter operating schematic

As discussed in Section 3.3, sludge conditioning must be optimized to achieve the desired degree of dewatering regardless of the sludge type and type of dewatering equipment used. To ensure successful vacuum filtration, the operator should follow the procedures outlined in Section 3.3 to condition and prepare the sludge for dewatering. The vacuum filter operating guidelines and their effects on filter performance are discussed below.

3.4121 Operating Guidelines. The applied vacuum will affect the degree and rate of sludge pick-up in the "formation zone" and will affect the quantity of water withdrawn from the sludge in the drying zone. In general, reduced vacuums will result in wetter cakes and less than optimum discharge characteristics. The operator should attempt to maintain *AS HIGH A VACUUM AS POSSIBLE* to obtain high degrees of dewatering.

The drum speed or the time required to make one complete cycle also controls the degree of dewatering. Typically, cycle times vary from 2 to 6 minutes and *THE LONGER THE CYCLE TIME THE HIGHER THE DEGREE OF DEWATERING.* Cycle time as controlled by drum speed affects sludge dewatering in two ways. First, it controls the rate of sludge pick-up and the thickness of the sludge mat in the "formation zone," and second, it controls the length of time the sludge remains in the "drying zone." As the cycle time is increased, the opportunity to pick up sludge from the trough and the time the sludge mat is subjected to a vacuum in the "drying zone" are increased. This generally results in drier cakes and improved discharge characteristics. The operator should maintain as low a drum speed as possible to obtain the highest degree of dewatering. The cycle time is dependent on the solids loading or net filter yield and the minimum speed that can be used depends on the filter area and the quantity of sludge to be processed. Obviously, if the number and/or size of the filters is not adequate to handle the entire sludge load at the lowest drum speed, the operator will have to maintain higher drum speeds. In addition to controlling the degree of dewatering, the drum speed also controls the net filter loading. As the drum speed increases, the net filter loading and the total quantity of sludge processed per day increases. The following example illustrates the determination of filter loading and filter yield.

EXAMPLE 37

Given: A 6-foot diameter by 10-foot long vacuum filter with a total surface area of 188 sq ft ($\pi \times 6$ foot $\times$ 10 foot) dewaters 4,500 lbs/day of primary sludge solids. The filter is operated for 7 hours per day at a drum cycle time of 3 minutes and produces a dewatered sludge of 25 percent thickened sludge (TS) with 95 percent solids recovery.

Find: The filter loading in lbs/hr/sq ft and filter yield in lbs/hr/sq ft.

Solution:

Known		Unknown
Vacuum Filter		
Diameter, ft	= 6 ft	1. Filter Loading, lbs/hr/sq ft
Length, ft	= 10 ft	
Surface Area, sq ft.	= 188 sq ft	2. Filter Yield, lbs/hr/sq ft
Sl Sol Loading, lbs/day	= 4500 lbs/day	
Filter Operation hrs/day	= 7 hrs/day	
Drum Cycle Time, min	= 3 min	
Dewatered Sludge Sol, %	= 25%	
Solids Recovery, %	= 95%	

Calculate the filter loading in pounds per hour per square foot.

$$\text{Filter Loading, lbs/hr/sq ft} = \frac{\text{Sl Sol Loading, lbs/day}}{\text{Fil Operation, hrs/day} \times \text{Area, sq ft}}$$

$$= \frac{4500 \text{ lbs/day}}{7 \text{ hrs/day} \times 188 \text{ sq ft}}$$

$$= 3.4 \text{ lbs/hr/sq ft}$$

Calculate the filter yield in pounds per hour per square foot.

$$\text{Filter Yield, lbs/hr/sq ft} = \frac{\text{Sl Sol Loading, } \frac{\text{lbs}}{\text{day}} \times \frac{\text{Recov, \%}}{100\%}}{\text{Fil Op, hr/day} \times \text{Area, sq ft}}$$

$$= \frac{4500 \frac{\text{lbs}}{\text{day}} \times \frac{95\%}{100\%}}{7 \text{ hr/day} \times 188 \text{ sq ft}}$$

$$= 3.2 \text{ lbs/hr/sq ft}$$

EXAMPLE 38

Given: Based on previous experimentation with the filter and sludge from Example 37, the operator knows that lowering the drum cycle to 2 minutes will produce a 30 percent dewatered sludge with 95 percent solids capture or recovery, but the filter yield will decrease to 1.7 lbs/hr/sq ft.

Find: The time the filter must be operated to process 4,500 pounds of primary sludge solids.

Solution:

Known		Unknown
Information given in Example 37		Time filter must be operated in hours per day
If drum cycle time reduced to 2 min,		
Dewatered Sl Sol, %	= 30%	
Solids Recovery, %	= 95%	
Filter Yield lbs/hr/sq ft	= 1.7 lbs/hr/sq ft	

Calculate the time the filter must be operated to process 4,500 pounds per day of primary sludge solids.

$$\text{Filter Yield, lbs/hr/sq ft} = \frac{\text{Sl Sol Loading, } \frac{\text{lbs}}{\text{day}} \times \frac{\text{Recov, \%}}{100\%}}{\text{Fil Op, hr/day} \times \text{Area, sq ft}}$$

Rearrange the terms.

$$\text{Filter Operation, hr/day} = \frac{\text{Sl Sol Loading, } \frac{\text{lbs}}{\text{day}} \times \frac{\text{Recov, \%}}{100\%}}{\text{Fil Yield, } \frac{\text{lbs/hr}}{\text{sq ft}} \times \text{Area, sq ft}}$$

$$= \frac{4500 \frac{\text{lbs}}{\text{day}} \times \frac{95\%}{100\%}}{1.7 \frac{\text{lbs/hr}}{\text{sq ft}} \times 188 \text{ sq ft}}$$

$$= 13.4 \text{ hours/day}$$

Therefore, the filter must be operated for 13.4 hours per day to produce a dewatered sludge cake of 30 percent solids when using a 2-minute cycle time.

The exact response (filter yield and dewatered sludge as percent sludge solids) of a particular sludge depends on the treatment plant. Experimentation is required to determine the filter yields and degrees of dewatering at different cycle times.

The depth of submergence of the drum within the trough affects the formation of the sludge mat on the media. In general, as the depth of submergence increases, more sludge solids are picked up and filter yields may increase somewhat. The depth of submergence should always be within the manufacturer's recommended range. In addition, the liquid level in the trough should never be maintained below a level which will cause a loss in vacuum. If the liquid level in the trough is too low, air will be pulled into the vacuum compartments and will result in a loss of vacuum and a subsequent loss of mat formation and sludge dewatering.

The material of construction for the filter media is selected based on experimentation with various cloth types. As the porosity (openings) of the media increases, the ability to capture suspended solids decreases because fine, low-density solids can pass directly through the media. Regardless of the type and size of media selected for a particular application, the operator must ensure adequate media cleaning via the washwater zone. If the media blinds with fine solids or chemical coatings, sludge will not be picked up in the trough (vat) in the sludge blanket formation zone and the vacuum filter will become inoperable.

3.4122 Normal Operating Procedure. The specific operation of a particular vacuum will vary somewhat, but the following procedures will be applicable for most operations:

1. Prepare chemicals in appropriate chemical tanks.
2. Transfer lime, if used, to a mixing tank to provide contact with the sludge and/or add the required amount of ferric chloride, if used.
3. Turn on the filter drum and the washwater to wet the entire belt.
4. Pull up tension.
5. Fill the trough to the operating level with the conditioned sludge.
6. Turn on the sludge mixer in the trough.
7. Turn on the vacuum pumps and filtrate pumps.
8. Adjust the drum speed and vacuum until the desired results are achieved.

Whenever the unit is shut down, the cloth should be thoroughly cleaned to reduce the possibility of plugging during subsequent operation. After shutdown, release cloth tension.

3.4123 Typical Performance. Table 3.19 summarizes typical vacuum filter operation and performance criteria for various sludge types.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 256.

3.41W What purpose does the agitator or mixer in the trough serve?

3.41X Explain what happens in the "mat formation" and "drying zones."

3.41Y Why does the filter media pass through a washing zone?

3.41Z List the factors that affect vacuum filtration.

3.41AA What vacuum should the operator maintain?

3.41AB Explain how cycle time or drum speed affects vacuum filter dewatering.

3.41AC Determine the *FILTER YIELD* (lbs/hr/sq ft) for a vacuum filter with a surface area of 300 sq ft. Digested sludge is applied at a rate of 75 GPM with a suspended solids concentration of 4.7 percent. The filter recovers 93 percent of the applied suspended solids.

3.41AD How does the porosity of the filter media affect vacuum filter performance?

3.4124 Troubleshooting. Successful vacuum filtration will result in a relatively clear filtrate and a relatively thick sludge mat that will readily discharge from the filter media. The most common problems that develop with vacuum filters are deteriorations in filtrate quality and wet cakes that are difficult to discharge from the belt.

If the filtrate quality is noted to contain more than the usual amount of solids, the operator should check the vacuum and

TABLE 3.19 TYPICAL PERFORMANCE OF VACUUM FILTERS

Sludge Type	Lime, lbs/ton[a]	$FeCl_3$, lbs/ton[a]	Thermal Conditioning	Vacuum, in. Hg[b]	Cycle, Min.	Yield, lbs Sol/hr/sq ft[c]	Cake, % TS[d]	Solids Recovery, %
Primary	50-150	25-50	—	15-30	2-6	4-12	24-40	85-95
Primary and Trickling Filter	—	—	LPO	15-30	2-6	4-8	30-45	85-95
Primary and Air-Act.	—	—	LPO	15-30	2-6	4-5	25-40	85-95
Digested Primary and Tr. Filter	200-600	—	—	15-30	2-6	4-8	25-35	85-95
	—	—	LPO	15-30	2-6	4-5	25-40	85-95
Digested Primary & Air-Act.	—	—	LPO	15-30	2-6	4-5	25-30	85-90

---

[a] lbs of chemical/ton of dry sludge solids. lbs/ton × 0.5 = gm of chemical/kg of dry sludge solids

[b] in. Hg × 2.54 = cm Hg

[c] lbs solids/hr/sq ft × 4.883 = kg/hr/sq m

[d] Thickened sludge

the condition of the filter media. The filter media can easily move out of alignment and often work their way free of the drum. If this happens, a proper seal will not develop between the media and drum and unfiltered sludge will be sucked from the trough and contaminate the filtrate. If the seal is broken between the media and drum, a loss of vacuum will develop when the unsealed point on the drum is subjected to a vacuum. The operator should check the vacuum gages for losses of vacuum and realign the filter media as required. If the filter media (cloth blanket) is misaligned, this is a major repair job and will require the unit to be shut down. A tear in the filter media will have the same effect as misalignment and the operator should repair or replace the media if it is defective.

A substantial reduction in cake dryness and/or discharge or filtrate characteristic will result from (1) inadequate chemical conditioning, (2) cycle times too low (drum speed too fast), or (3) media blinding. The operator should check the condition of media and increase the washwater rate, or turn off the sludge feed and wash the belt if it is laden with solids as it exits the washing zone. A clogged media will usually develop when poor mat formation occurs in the pick-up zone. Whatever solids are picked up will not effectively drain in the drying zone and a wet cake will develop.

If the media is clean and a good seal is developed, a decrease in sludge dryness and discharge characteristics could result from high drum speeds or improper conditioning. If possible, the drum speed should be lowered to afford more drying time, and the chemical mixing and addition system should be checked for malfunctions. The operator should also be aware that drastic changes in the influent sludge characteristics could affect the chemical dosage and the degree of dewatering. If the influent sludge appears to be thicker than normal, the operator must increase the rate of chemical addition to match the increase in influent solids.

Table 3.20 summarizes the most common operational problems and the usual corrective measures taken to maintain good vacuum filter dewatering.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 256 and 257.

3.41AE What can cause a loss in vacuum and how will such a loss affect filter performance?

3.41AF If the sludge is not picked up in the mat formation zone, what should the operator do?

3.41AG How can the operator increase cake dryness?

3.42 Centrifugation

3.420 Process Description

Centrifuge designs for dewatering sludge include batch-operated basket centrifuges and continuous-flow scroll centrifuges. Factors affecting centrifugation, operating criteria and troubleshooting were described in detail in the thickening section (3.1) of this manual. The reader should refer to Section 3.1 for a review of the mechanics of centrifugation. The main differences between centrifugal thickening and centrifugal dewatering are that the concentration of feed sludge is somewhat higher for dewatering than for thickening, and that a drier cake is the usual goal for dewatering. The operator may therefore have to maintain a higher differential (relative) scroll speed when dewatering because of the higher solids loading, but the principles of centrifugation remain the same as previously discussed.

3.421 Typical Performance

Table 3.21 summarizes typical centrifuge operating criteria, conditioning requirements, and performance data for various sludge types.

Usually, the physical size of the centrifuge will govern the maximum through put for a particular sludge and, in general, the exact response of a particular sludge depends on the treatment plant.

Troubleshooting techniques for basket and scroll centrifuge dewatering are identical to those already outlined in Section 3.1.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 257.

3.42A Why are higher scroll speeds usually required to dewater sludges as compared to sludge thickening?

3.42B A scroll centrifuge is used to dewater 60 GPM of digested primary sludge at a concentration of 3.0 percent sludge solids. A liquid polymer is used for conditioning. The polymer solution is 2.5 percent and 2 GPM are added to the sludge stream. What is the hydraulic loading (GPH), the solids loading (lb SS/hr) and the polymer dosage (lb liq/ton)?

3.42C A 48-inch diameter basket centrifuge is used to dewater 50 GPM of digested primary sludge. The feed is at a concentration of 2.7 percent sludge solids and

TABLE 3.20 TROUBLESHOOTING VACUUM FILTERS

Operational Problem	Possible Causes	Check or Monitor	Possible Solution
1. Loss of Vacuum	1. a. Filter media misaligned b. Tear in filter media c. Trough empty d. Vacuum pumps inoperative	1. a. Media alignment b. Media condition c. Level in trough d. Operation of vacuum pumps	1. a. Realign media b. Repair/replace media c. Fill trough d. Repair and/or turn on pumps
2. Poor filtrate quality	2. a. Same as 1a and 1b b. Insufficient conditioning	2. a. Same as 1a and 1b b. Conditioning system	2. a. Same as 1a and 1b b. Increase dosage or degree of conditioning
3. Wet cake and poor discharge	3. a. Same as 1a, 1b and 1d b. Drum speed too high c. Insufficient conditioning	3. a. Same as 1 b. Drum speed c. Conditioning system	3. a. Same as 1 b. Lower drum speed c. Increase dosage or degree of conditioning
4. Poor mat formation	4. a. Same as 1, 2, and 3 b. Clogged media	4. a. Same as 1, 2 and 3 b. Media condition	4. a. Same as 1, 2, and 3 b. Clean media

polymers are added to achieve 95 percent suspended solids recovery. The average concentration of solids stored within the basket is 23 percent. The feed time is automatically set at 17 minutes. Is the feed time too long, too short, or OK? Assume the basket has a solids storage capacity of 16 cubic feet.

3.42D A basket centrifuge is used to dewater digested secondary sludge. On a routine check, the operator notices that the centrate quality is poor but the discharge solids are dry. What should the operator check and what action should be taken to produce a clean centrate?

3.43 Sand Drying Beds

The use of sand drying beds to dewater wastewater sludges is usually limited to small or medium-sized plants (less than 5 MGD or 19,000 cu m/day) because of land restrictions. Drying beds usually consist of 4 to 9 inches (10 to 23 cm) of sand placed over 8 to 20 inches (20 to 50 cm) of graded gravel or stone. Sludge is placed on the beds in 12 to 18 inch (30 to 45 cm) layers and allowed to dewater by drainage through the sludge mass and supporting sand, and by evaporation from the surface exposed to the atmosphere. An underdrain system composed of a lateral network of perforated pipes or trenches can be used to collect the filtrate for subsequent recycle to the plant headworks. After drying, the dewatered sludge is removed by manual shoveling (forks) for further processing or ultimate disposal. Sludge drying beds are usually not used for sludges that have been stabilized or conditioned by wet oxidation because of the odorous nature of thermally heated sludge.

3.430 Factors Affecting Sand Drying Beds

The design, use, and performance of drying beds are affected by many factors. These include (1) sludge type, (2) conditioning, (3) climatic conditions, (4) sludge application rates and depths, and (5) dewatered sludge removal techniques.

As is the case with mechanical dewatering devices, the type of sludge applied and the effectiveness of chemical conditioners can determine the degree of dewatering and the operation of the beds. Since the majority of dewatering is by drainage through the support sand, the sludge has to be adequately conditioned to flocculate the sludge solids and release free water. Care must be taken to prevent chemical overdosing for two reasons, (1) media (sand) blinding with unattached polymer may develop, and (2) large floc particles that settle too rapidly may also blind the media. Whatever the mechanism for blinding, the net result will be the same. The liquid portion of the sludge will be unable to drain through the bed and dewatering will be by evaporation only. The time required to evaporate water is substantially greater than the time required to remove water by a combination of evaporation and drainage.

Chemical requirements, pre-screening requirements, and the response of sludges to sand drying operations are generally determined by laboratory, pilot and/or full-scale experimentations.

Climatic conditions are very important to an efficient sand drying bed operation. After all the water that can be removed by drainage is complete, evaporation is the only mechanism available for further dewatering. As climatic conditions vary from inclement and humid to dry and arid, so does the rate of evaporation and consequently the time required to achieve the desired degree of dewatering. In wet or cold climates, the sand beds are usually covered with greenhouse-types of enclosures to protect the drying sludge from rain and to reduce the drying period during cold weather. Such enclosures should be well ventilated to promote evaporation. They also can serve to control odors and insects.

The operator has little, if any, control over the sludge type and characteristics, no control over climatic conditions and physical size of the sand beds, but can control, to some extent, the depth of sludge application and dewatered sludge removal techniques.

3.431 Operating Guidelines

The physical size of sand drying beds is based on the amount of sludge to be dried each year. In general, sand beds are loaded at rates of 10 to 35 lbs of sludge solids/yr/sq ft (50 to

TABLE 3.21 TYPICAL PERFORMANCE OF CENTRIFUGES

Sludge Type	Centrifuge Type	Conditioning		Flow, GPM[b]	Solids Load, lbs/hr[c]	Cake, % TS[d]	Solids Recovery, %
		Polymer, lbs/ton[a]	Thermal				
Primary	Scroll	0-5	—	20-150	200-1500	25-35	30-95
Primary	Scroll	0-5	LPO	20-150	200-1500	25-40	50-95
Secondary	Scroll	0-15	—	20-150	100-700	6-9	30-95
Secondary	Scroll	0-7	LPO	20-150	100-700	20-30	70-95
Secondary	Basket	0-10	—	20-70	70-350	6-9	50-95
Secondary	Basket	0-4	LPO	20-70	70-350	20-30	70-95
Dig. Pri.	Scroll	0-15	—	20-150	200-1500	20-25	30-95
Dig. Pri.	Scroll	0-5	LPO	20-150	200-1500	20-30	70-95
Dig. Pri.	Basket	0-15	—	35-50	200-500	20-25	70-95
Dig. Sec.	Scroll	0-40	—	20-150	200-1500	6-12	30-95
Dig. Com.[e]	Scroll	0-20	—	20-150	200-1500	10-25	30-95
Dig. Com.[e]	Basket	0-20	—	35-50	200-500	10-20	50-95

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[a] lbs of dry polymer/ton of dry sludge solids. lbs/ton × 0.5 = gm of polymer/kg of dry sludge solids

[b] GPM × 5.45 = cu m/day

[c] lbs/hr × 0.454 = kg/hr

[d] Thickened Sludge

[e] Digested Primary + Digested Combined

170 kg/yr/sq m) for open drying beds and 20 to 45 lbs of sludge solids/yr/sq ft (100 to 220 kg/yr/sq m) for covered drying beds. Obviously, as the loading rate decreases, the time required to dewater the sludge decreases as does the potential for blinding of the bed. The operator should control loading rates according to the total area of bed available and the estimated quantity of sludge production. The operator should also provide for a standby capacity of 10 percent additional area, if possible, to meet unexpected increases in sludge loads and to allow for down time for operational problems. If sufficient bed area is not available to allow for standby capacity, auxiliary mechanical dewatering equipment or liquid sludge haulers should be available for emergency situations.

EXAMPLE 39

Given: An operator at a treatment plant has two sand beds available for dewatering experiments. Each bed has dimensions of 200 feet long by 25 feet wide. Sludge is applied to Bed A to a depth of 3 inches and to Bed B to a depth of 9 inches. Bed A requires six (6) days to dry and one (1) day to remove the sludge for another application. Bed B requires 21 days to dry and one (1) day to remove the sludge for another application. The applied sludge is at a concentration 3 percent sludge solids.

Find:
1. The total gallons and lbs of sludge applied per application for Bed A and Bed B.
2. The loading rates (lbs/yr/sq ft) for Bed A and Bed B assuming repeated applications are made on each bed with no operational or maintenance down time.
3. Which application depth should be used.

Solution:

Known	
Two Sand Beds	
Length, ft	= 200 ft
Width	= 25 ft
Sl Depth, in	= 3 in (Bed A)
Sl Depth, in	= 9 in (Bed B)
Drying Time Bed A, days	= 6 days
Bed B, days	= 21 days
Sludge Removal, days	= 1 day
Sludge Solids, %	= 3%

Unknown

1. Sludge Applied, gallons/application and pounds/application for both Beds A and B.
2. Loading Rates, lbs/yr/sq ft for both Beds A and B.
3. Which application depth should be used?

1. Determine the sludge applied in gallons per application and pounds per application for both Beds A and B.

BED A

$$\text{Sludge Applied, gal/application} = \frac{\text{L, ft} \times \text{W, ft} \times \text{D, in/apl}}{\text{12 in/ft}} \times \frac{\text{7.48 gal}}{\text{cu ft}}$$

$$= \frac{\text{200 ft} \times \text{25 ft} \times \text{3 in/apl}}{\text{12 in/ft}} \times \frac{\text{7.48 gal}}{\text{cu ft}}$$

$$= \text{9,350 gal/application}$$

$$\text{Sludge Applied, lbs/application} = \text{Sl Appl}, \frac{\text{gal}}{\text{apl}} \times \frac{\text{8.34 lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}$$

$$= 9{,}350\ \frac{\text{gal}}{\text{apl}} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{3.0\%}{100\%}$$

$$= \text{2,340 lbs/application}$$

BED B

$$\text{Sludge Applied, gal/application} = \frac{\text{L, ft} \times \text{W, ft} \times \text{D, in/apl}}{\text{12 in/ft}} \times \frac{\text{7.48 gal}}{\text{cu ft}}$$

$$= \frac{\text{200 ft} \times \text{25 ft} \times \text{9 in/apl}}{\text{12 in/ft}} \times \frac{\text{7.48 gal}}{\text{cu ft}}$$

$$= \text{28,050 gal/application}$$

$$\text{Sludge Applied, lbs/application} = \text{Sl Appl}, \frac{\text{gal}}{\text{apl}} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{\text{Sl Sol, \%}}{100\%}$$

$$= 28{,}050\ \frac{\text{gal}}{\text{apl}} \times 8.34\ \frac{\text{lbs}}{\text{gal}} \times \frac{3.0\%}{100\%}$$

$$= \text{7,018 lbs/application}$$

2. Determine the loading rates for the sludge applied in pounds per year per square foot for both Beds A and B.

BED A

$$\text{Loading Rate, lbs/yr/sq ft} = \frac{\text{Sl Appl, lbs/apl} \times \text{365 days/yr}}{\text{L, ft} \times \text{W, ft} \times \text{Cycle, days/apl}}$$

$$= \frac{\text{2340 lbs/apl} \times \text{365 days/yr}}{\text{200 ft} \times \text{25 ft} \times \text{(6 days + 1 day)/apl}}$$

$$= \text{24.4 lbs/yr/sq ft}$$

BED B

$$\text{Loading Rate, lbs/yr/sq ft} = \frac{\text{Sl Appl, lbs/apl} \times \text{365 days/yr}}{\text{L, ft} \times \text{W, ft} \times \text{Cycle, days/apl}}$$

$$= \frac{\text{7018 lbs/apl} \times \text{365 days/yr}}{\text{200 ft} \times \text{25 ft} \times \text{(21 days + 1 day)/apl}}$$

$$= \text{23.3 lbs/yr/sq ft}$$

3. Which application depth should be used?

Based on the data given and the above analysis, there is no substantial difference in the amount of solids that can be applied per year for application depths of 3 inches and 9 inches. The operator should choose the 9-inch application because it will result in less operator time. A 3-inch application would require the operator to refill and possibly remove solids every 7 days while a 9-inch application will require operator attention every 22 days.

The preceding example *ONLY* illustrates the calculations necessary to determine loading rates and it should *NOT* be misinterpreted that high application depths are more efficient than low application depths as a result of these calculations. The operator should go through the above analysis for a particular sludge and specific data to determine the optimum depth of application. Usually, greater depths of digested sludge are applied and the drying times are longer than used in this example.

Sludge removal from sand drying beds should be done so as to remove as little of the sand media as possible and care should be taken to avoid compacting the sand bed. Heavy equipment should not be allowed on the bed. Provisions should be made to remove dewatered sludge by surface scrapers or collectors that are mounted on the vertical walls of the bed or on the access road between the beds. Compaction of the bed will result in reduced drainage rates, longer drying times and may increase the potential for plugging.

3.432 Normal Operating Procedures

The sludge should be applied to the bed as evenly as possible and should be done with minimal upsetting of the bed surface. This is best accomplished by applying the sludge through an inlet distribution assembly which may consist of troughs and weirs to apply the sludge evenly and with as little turbulence as possible. Be sure to flush the sludge out of the pipe and leave one end open for any gas produced by anaerobic decomposition to escape. Some operators make a large two-wheel "pizza cutter" out of disc harrows, or a tine-type drag device, either of which is dragged across the sludge as soon as it begins to "fetch up." This promotes cracking along these lines which allows operators to fork out easily handled sized pieces of dried sludge. Remove the sludge from the bed when it reaches a dryness that will allow for easy removal. Scrape and smooth the surface of the bed with a rake to prepare the drying bed for more sludge.

3.433 Typical Performance

Table 3.22 summarizes typical operating guidelines and performance data for sand drying of wastewater sludges.

The final concentration to which the sludge can be dried is dependent on the climatic conditions and time the sludge remains in the bed after the majority of water has drained through the sand. In general, the sludge is dried to the point where it can easily be removed from the bed. If the sludge is removed when it is relatively wet and sticking to the bed surface, large quantities of sand also will be removed.

TABLE 3.22 TYPICAL PERFORMANCE OF SAND BEDS

	Loading, lb SS/sq ft[a]		Cake, % TS[b]	Solids Recovery, %
	Open Bed	Covered Bed		
Digested Primary	20 - 35	20 - 45	30-70	95 - 99
Digested Secondary	10 - 20	10 - 25	30-50	95 - 99
Digested Combined	10 - 25	10 - 35	30-70	95 - 99

[a] lb/sq ft × 4.883 = kg/sq m

[b] Thickened sludge

Sand bed operations are more of an art than a science because of the large number of uncontrolled variables. Even though sand beds are a common method of sludge dewatering, it is difficult to list typical operation and performance data with a reasonable degree of certainty.

3.434 Troubleshooting

Sand drying beds are relatively simple to operate and the only problem that appears to develop at most installations is plugging of the media (sand) surface. When sludge is applied, the majority of water should drain within the first 3 to 10 days after the application. If poor drainage is evident by small filtrate quantities and a slow rate of drop of the liquid surface, the operator can assume the media is plugged. If sufficient area or standby capacity is available, the affected bed(s) should be allowed to dry by evaporation. After the sludge is dried and removed, the operator should rake the surface of the bed and might remove the upper 2 to 3 inches (5 to 8 cm) of sand and replenish with fresh sand if excessive blinding is evident. If sufficient capacity is not available to allow time for the sludge in the affected bed to dry by evaporation, the operator should pump the sludge out of the bed and clear or replace the upper layer of sand.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 257 and 258.

3.43A Why are sand drying beds not commonly used for wet oxidized sludges?

3.43B List the factors that affect sand drying bed performance.

3.43C Why should overdosing with chemicals, particularly polymer, be avoided?

3.43D Why might primary sludge from the bottom of digesters require pre-screening?

3.43E Why are drying beds sometimes covered?

3.43F A 150-foot long by 30-foot wide sand drying bed is loaded at 15 lbs/yr/sq ft. One application of sludge is made per month (12 applications per year). Determine the depth (in) of each application if the sludge has a concentration of 3.0 percent sludge solids.

3.43G How should an operator determine the most desirable depth of sludge to be applied to sand beds?

3.43H Why should sand bed compaction be avoided?

3.43I Why should the sand bed surface be raked after sludge is removed?

3.43J What determines the final concentration to which sludge is dewatered on sand beds?

3.43K What is the major problem that is encountered when operating sand drying beds?

3.44 Surfaced Sludge Drying Beds

3.440 Need for Surfaced Drying Beds

Sludge drying beds using gravel and sand with an underlying pipe system for bed drainage have a limitation of manual cleaning with forks or shovels to remove the dried sludge. Equipment such as tractors with front end loaders cannot be used to remove dry sludge from sand beds because the equipment would break the pipe underdrains, compact the sand bed, or mix the sand and gravel layers. Some operators lay planks or mats on the sand bed surface to distribute the weight of cleaning equipment. After the sludge removal operation is complete, the operator simply removes the planks or mats leaving the sand bed undisturbed. Surfaced drying beds of either blacktop or concrete have been used to facilitate easier sludge removal by the use of skip loaders. One advantage of a surfaced bed is the ability to speed up sludge drying.

3.441 Layout of Surfaced Drying Beds (Fig. 3.20)

Surfaced drying beds are designed to allow the use of mechanical sludge removal equipment. Other design considerations include the application of digested sludge to be dried and the drainage of water released from the sludge being dried. Drying beds are rectangularly shaped with widths of 40 to 50 feet (12 to 15 m) and lengths of 100 to 200 feet (30 to 6 m). A two-foot high retaining wall around the outside of the bed contains the sludge.

The actual size of a drying bed depends on the sludge produced by the treatment plant. A plant with small flows, less than 2 MGD (7,570 cu m/day), and with secondary treatment may require only four 40 by 100 feet (12 by 30 m) drying beds for sludge handling purposes. However, a 10 MGD (37,850 cu m/day) plant with activated sludge and no solids thickening processes before sludge digestion may require 20 drying beds 50 by 200 feet (15 by 60 m) to provide adequate sludge handling capabilities. The drying beds are usually sized so that one bed can be filled with sludge from the digesters to an 18-inch (45 cm) sludge depth in an eight-hour period.

The drying bed is provided with a 4-inch (100 mm) or 6-inch (150 mm) drain line down the center of the bed and 18 inches (45 cm) to 30 inches (75 cm) below the surface of the drying bed. The drain line is either a perforated pipe or a pipe with pulled joints (space between joints) (Fig 3.21). The trench in

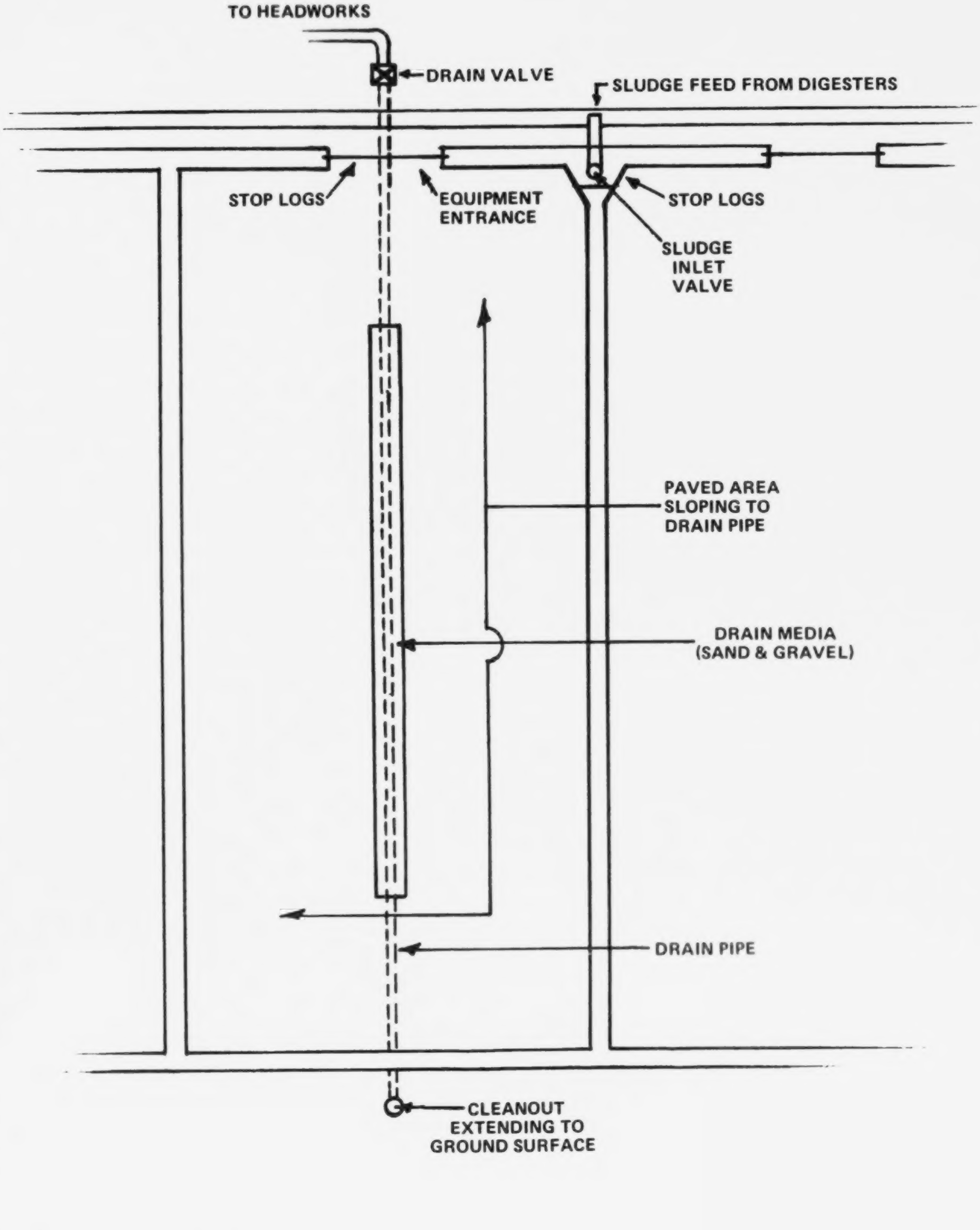

TO HEADWORKS
DRAIN VALVE
SLUDGE FEED FROM DIGESTERS
STOP LOGS
EQUIPMENT ENTRANCE
STOP LOGS
SLUDGE INLET VALVE
PAVED AREA SLOPING TO DRAIN PIPE
DRAIN MEDIA (SAND & GRAVEL)
DRAIN PIPE
CLEANOUT EXTENDING TO GROUND SURFACE

Fig. 3.20 Surfaced sludge drying bed (top view)

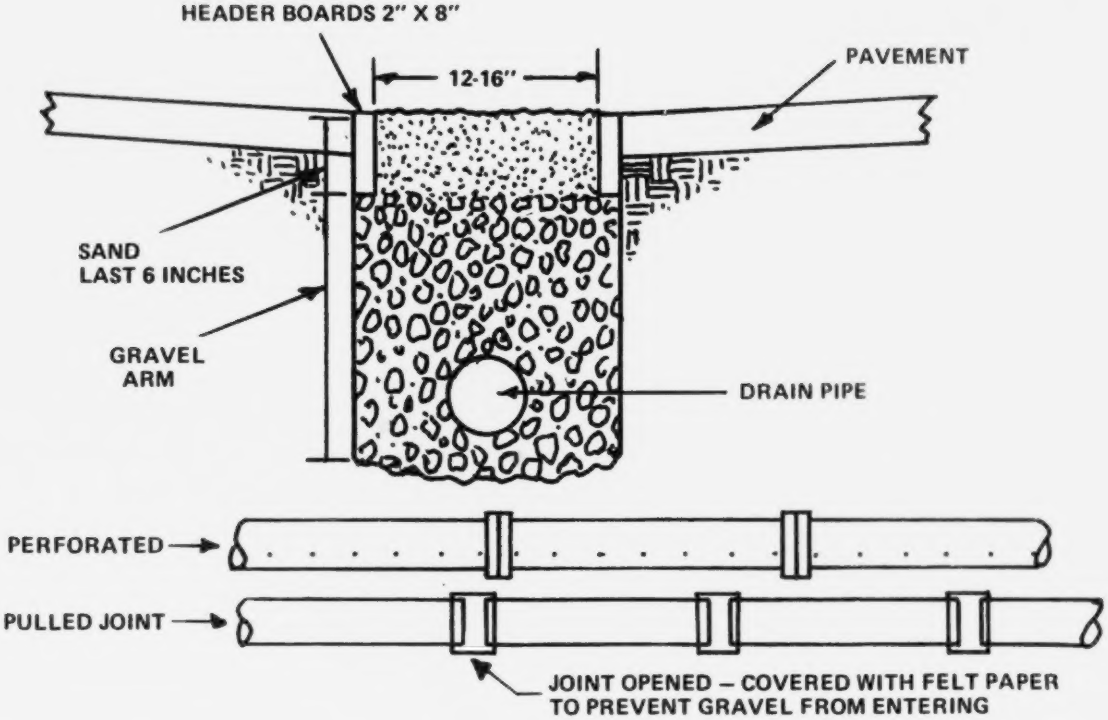

HEADER BOARDS 2" X 8"
12-16"
PAVEMENT
SAND
LAST 6 INCHES
GRAVEL
ARM
DRAIN PIPE
PERFORATED
PULLED JOINT
JOINT OPENED – COVERED WITH FELT PAPER
TO PREVENT GRAVEL FROM ENTERING

Fig. 3.21 Drainage details

which the drain pipe is placed is filled with gravel and sand that serve as a media to filter solids out of the drainage water.

The drying bed drain pipe to the plant headworks is equipped with a valve outside of the bed for isolation of the drying bed. At the other end (high end) of the drain pipe, the line is extended to the ground surface (grade) and a cleanout is installed to allow cleaning of the drain line. Digested sludge is usually applied to the drying bed through a six-inch (150 mm) sludge feed line with a control valve or a box arrangement as shown in Figure 3.20.

Equipment access to the bed is through a 12-foot (3.6 m) opening in the end wall. The opening is closed off with 2 × 12-inch (5 × 30 cm) planks (stop logs) to seal the opening when the drying bed is being filled and in use.

3.442 Operation

When placing a sludge drying bed into operation the following tasks should be performed:

1. Remove the drain line cleanout on the bed to be filled and flush the drain line with water.
2. Close the valve on the drain line discharge after flushing the drain line.
3. If the drain media is filled with gravel only, fill the drain line and filter area with water until the gravel is flooded. This will prevent sludge from entering the voids (empty spaces) in the gravel over the drain line during filling of the drying bed. Beds with gravel and an overlying sand upper layer do not require flooding before filling with digested sludge. However, the sand layer should be loosened and raked level before applying sludge to the drying bed. After flooding the drain media, make sure the cleanout cap is replaced and secured.
4. Install the 2 × 12-inch (5 × 30 cm) stop logs in the equipment entrance opening to the bed. To seal the ends where the stop logs fit into the wall slot, use rags or burlap sacks wrapped around each end of the stop log and along the bottom of the stop log next to the paving. Sealing is necessary to prevent sludge leaking from the bed during the filling operation and the first days of drying. Sand or soil also may be used to form a small dam to prevent leaking. If the drying bed being filled has a gate for entrance to an adjacent bed that is not to be filled, seal the stop logs in this gate to prevent leakage.

   WARNING: NEVER SMOKE NEAR A SLUDGE DRYING BED THAT IS BEING FILLED OR HAS BEEN FILLED RECENTLY BECAUSE THE GASES FROM THE SLUDGE COULD FORM AN EXPLOSIVE MIXTURE.

5. Select the digester that sludge is to be withdrawn from and close feed valves to all drying beds except to the drying bed to be filled. Start sludge flowing from the digester to the drying bed by opening the proper valves.

   Control the sludge feed to the drying bed at the drying bed inlet valve. This allows you to observe the flow of sludge and rate of sludge application. The sludge should not be applied too fast to the bed because it may cause coning in the digester. When coning occurs, only the water will be drawn which will greatly extend the drying time. Eight to 12 hours may be required to fill a bed 40 by 100 feet (12 by 20 m) 18 inches (45 cm) deep at the side wall with sludge having a 6 to 8 percent solids content.

   Samples should be taken of the applied sludge thirty minutes after the start of the filling by placing 100 to 200 ml of sludge in a 1,000 ml beaker. An additional 100 to 200 ml sample is placed in the same beaker every hour thereafter while filling the drying bed. Always use the same size sample. Upon completion of filling the bed, the 1,000 ml beaker should be full of sludge from samples taken during the filling time.

   When the bed is filled to the desired level (usually 6 to 18 inches (15 to 45 cm) deep at the side walls), close the sludge feed valve at the digester. If no more sludge is to be withdrawn for at least a week, the sludge line should be cleared of sludge and flushed with water to prevent plugging of the line. Always leave the valve open at the filled drying bed, or another empty drying bed, to prevent gas from building up in the line and damaging the pipes, valves, or fittings.

6. Dewatering the drying bed. Mix the contents in the 1,000 ml sample beaker. Remove a 200 to 300 ml portion for laboratory analysis. Leave the remaining portion of sludge and the beaker sitting on the wall of the sludge drying bed. If the wastewater plant is staffed for 24-hour operation, an operator should check the beaker every four hours looking for signs of water-sludge separation.

   Water-sludge separation usually occurs in 12 to 24 hours after the sludge has been applied to the drying bed. The sludge will rise to the surface leaving a 10 to 40 percent portion by volume of water under the sludge. When this occurs, the drying bed drain line valve is partially opened to drain off the water from the drying bed. The sample beaker can then be returned to the laboratory. The water-sludge separation will not continue for more than several hours because the sludge will resettle to the bottom. If the sludge resettles, a large percentage of the water will move back into the sludge or to the surface of the sludge in pools. These pools will take a considerable amount of time to evaporate from the sludge. To hasten sludge drying, open the drain valve when the sludge sample shows that the water-sludge separation has occurred. This procedure has reduced the sludge volume in a drying bed by as much as 30 percent during the first day of drying.

   Sludge drying may be further hastened after a crust has formed on the sludge surface and has started to crack. Mix or break down the sludge by driving equipment through the drying bed to expose new sludge to surface evaporation.

3.443 Cleaning the Drying Bed

When the sludge on the bed has dried, the stop logs are removed and a tractor equipped with a front bucket (skip loader) is used to scoop up the sludge and remove it from the drying bed. The equipment operator should not drive on or across the drain trench because it will damage the trench or the drain pipe.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 258.

3.44A What is a limitation of using sand drying beds?

3.44B How would you start to fill a surfaced drying bed that has gravel only in the drainage trench?

3.44C What should be done when water-sludge separation is observed in a beaker containing digested sludge that is sitting on the wall of the sludge drying bed?

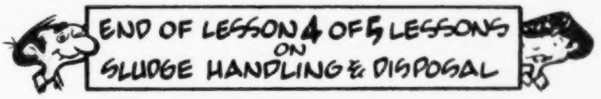
3.45 Dewatering Summary

Successful dewatering requires that (1) the operator be very familiar with the operation of the particular dewatering device(s) used, (2) sludge conditioning be optimum, and (3) the influent sludge be as thick and consistent as possible.

QUESTION

Write your answers in a notebook and then compare your answers with those on page 258.

3.45A How can an operator have a successful sludge dewatering program?



DISCUSSION AND REVIEW QUESTIONS

Chapter 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 4 of 5 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 3.

18. The degree of dewatering and the sludge solids removal efficiency for pressure filters are influenced by what factors?
19. How would you determine filtration time for a pressure filter?
20. What could be the cause or problem if a majority of the sludge passes through the filter without building up between the plates?
21. How would you determine the speed of the belt on a belt filter press?
22. How would you attempt to correct the cause of poor filtrate quality from a vacuum filter?
23. Why must care be taken to avoid chemical overdosing of sludges applied to sand drying beds?
24. Why should no smoking be allowed around drying beds while digested sludge is being applied or shortly thereafter?

CHAPTER 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 5 of 5 Lessons)

3.5 VOLUME REDUCTION

3.50 Purpose of Volume Reduction

Drying of wastewater sludges beyond the level attained by normal dewatering methods usually results in a product that can be marketed as a fertilizer or soil conditioner and may improve the economy of subsequent processes. For example, drying might be a feasible and required step to render sludges, especially those that are difficult to dewater, suitable for landfill disposal or may improve the overall efficiency of subsequent incineration processes.

Drying or incineration of wastewater sludges results in a net reduction of the sludge mass and are therefore termed *VOLUME REDUCTION PROCESSES.* The distinction between drying and incineration is that *DRYING* removes water from sludge *WITHOUT* the *COMBUSTION* (burning) of solid material.

Volume reduction is accomplished by a variety of methods including composting, direct and indirect heat drying and incineration. In addition to substantially reducing the volume of the sludge mass, heat drying and incineration processes should result in a complete destruction of pathogenic organisms due to the high temperatures maintained.

3.51 Composting (Also see Section 3.6220)

Composting results in the decomposition of organic matter by the action of *THERMOPHILIC*[38] facultative aerobic microorganisms to sanitary, nuisance-free, humus-like material. Composting is a biological process and requires that a suitable environment be established and maintained to ensure the survival and health of this group of bacteria. In order to create a suitable environment, several criteria must be met.

First, composting of wastewater sludges requires that these sludges be blended with previously composted material or bulking agents such as sawdust, straw or wood shavings. This blending process should produce a fairly uniform, porous structure in the composting material to improve aeration. The bulking material also provides control of the initial moisture content. Second, aeration must be sufficient to maintain aerobic conditions in the composting material. Third, proper moisture content and temperatures must be maintained. Microorganisms require moisture to function, but too much moisture can cause the process to become anaerobic and/or reduce the composting temperature below that which is suitable for the bacteria.

Composting generally falls into two categories: (1) windrow and (2) mechanical. The most common method of sludge composting is by windrow operation (Figure 3.22) and will be the only one discussed here. Mechanical composters are relatively untried on wastewater sludges and sufficient data do not currently exist for accurate evaluation and reliable operating procedures.

Windrow composting is generally limited to digested sludge and consists of collecting dewatered digested sludge, mixing it with previously composted material or bulking agents, and forming windrow piles. Typical windrow stack (pile) dimensions and spacing between stacks are shown in Figure 3.23. Specialized machinery such as "Flow-Boy"-type trailers can form windrows and at the same time mix dewatered sludge with compost material or bulking agents.

The initial moisture content of the blend of the dewatered sludge and bulking agents or compost should be approximately 45 to 65 percent moisture. After formation of the windrows, the stacks should be turned once or twice daily during the first five days to begin the compost action and to ensure a uniform mixture. Thereafter, the windrows should be turned anywhere from once per day to once a week to provide aeration and to encourage drying by exposing the compost material to the atmosphere. After the process is complete, the compost product must be loaded onto trucks for disposal and/or recycling. This can be accomplished by a variety of equipment including skip loaders and specially designed compost loaders.

Chemically stabilized and wet oxidized sludges are generally not suited for compost operations. Chemical stabilization produces environments that are unsuitable for microorganism survival and usually will not support the life of composting bacteria unless the sludges are neutralized and favorable conditions exist. Sludge that has been stabilized by wet oxidation can be composted, but noxious odors will more than likely develop in and around the compost operation. Unless provisions are made to house the compost area and scrub the exhaust gases, a severe lowering of air quality could develop and lead to numerous odor complaints.

3.510 Factors Affecting Composting

The time required to complete the composting process and the efficiency of the operation depend on many factors. These include: (1) sludge type, (2) initial moisture content and uniformity of the mixture, (3) frequency of aeration or window turning (4) climatic conditions, and (5) desired moisture content of the final product.

The type of digested sludge to be treated in a compost facility can drastically affect performance and operation. Primary and secondary sludges can be treated by compost processes, but the plastic nature of dewatered secondary sludge and increased moisture content make them more difficult to compost than primary sludge. The difficulties arise with secondary sludge because greater efforts have to be put into mixing with compost material or bulking agents to produce an evenly blended, porous mixture. Dewatered secondary sludges tend to clump together and form "balls" when they are blended with compost material. The balls that are formed within the windrows readily dry on the outer surface but remain moist on the inside. Occasionally, this creates anaerobic conditions leading to odor production and a lower composting temperature. The problem is further complicated when large quantities of polymer are used in the dewatering step because of the sticky nature of polymers.

The initial moisture content and homogeneity (evenness) of the mixture are important considerations in starting the compost process. These factors depend on sludge type, use of polymers as discussed above, and the effectiveness of the blending operation.

The quantity of compost product that must be blended with dewatered sludge to produce an initial moisture of 45 to 65 percent depends on the concentration of the dewatered sludge and the moisture content of the recycled compost material. The following examples show how to calculate the amount of compost required for blending purposes.

EXAMPLE 40

Given: A 5 MGD plant produces 4,100 lbs/day of dewatered digested primary sludge. The dewatered sludge is at a concentration of 30 percent thickened sludge (TS). Final compost product at the plant has a moisture content of 30 percent.

Find: The total pounds of compost that must be blended with the dewatered sludge to produce a moisture content of the mixture of 50 percent.

Solution:

Known		**Unknown**
Flow, MGD	= 5 MGD	Pounds of compost blended daily with dewatered sludge to produce a mixture with 50 percent moisture content.
Sludge, lbs/day (dewatered digested primary sludge)	= 4100 lbs/day	
Dewatered Sl Sol, %	= 30% Solids	
Final compost, %	= 30% moisture (70% solids)	

---

[38] *Thermophilic (thermo-FILL-lik). Hot temperature bacteria. A group of bacteria that grow and thrive in temperatures above 113°F (45°C). The optimum temperature range for these bacteria in anaerobic decomposition is 120°F (49°C) to 135°F (57°).*

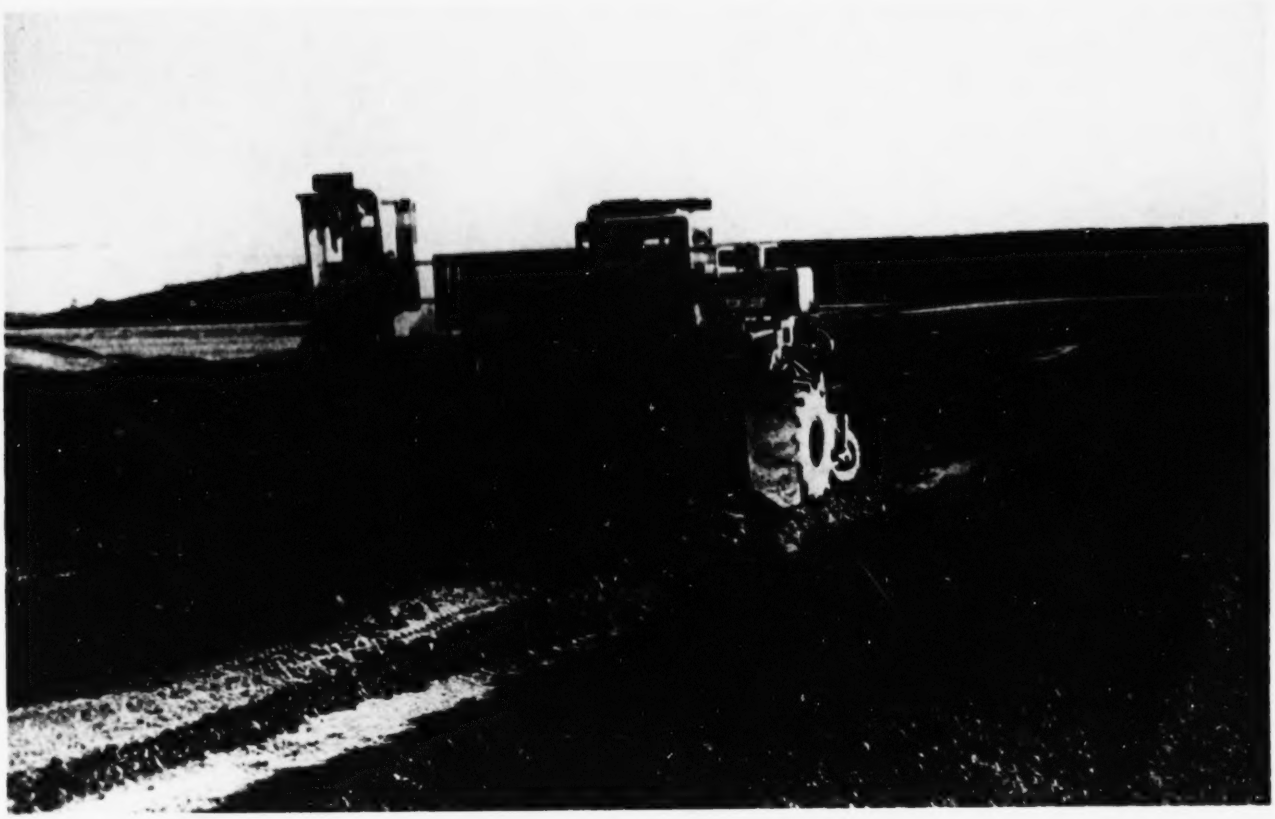


Fig. 3.22 Windrow composting

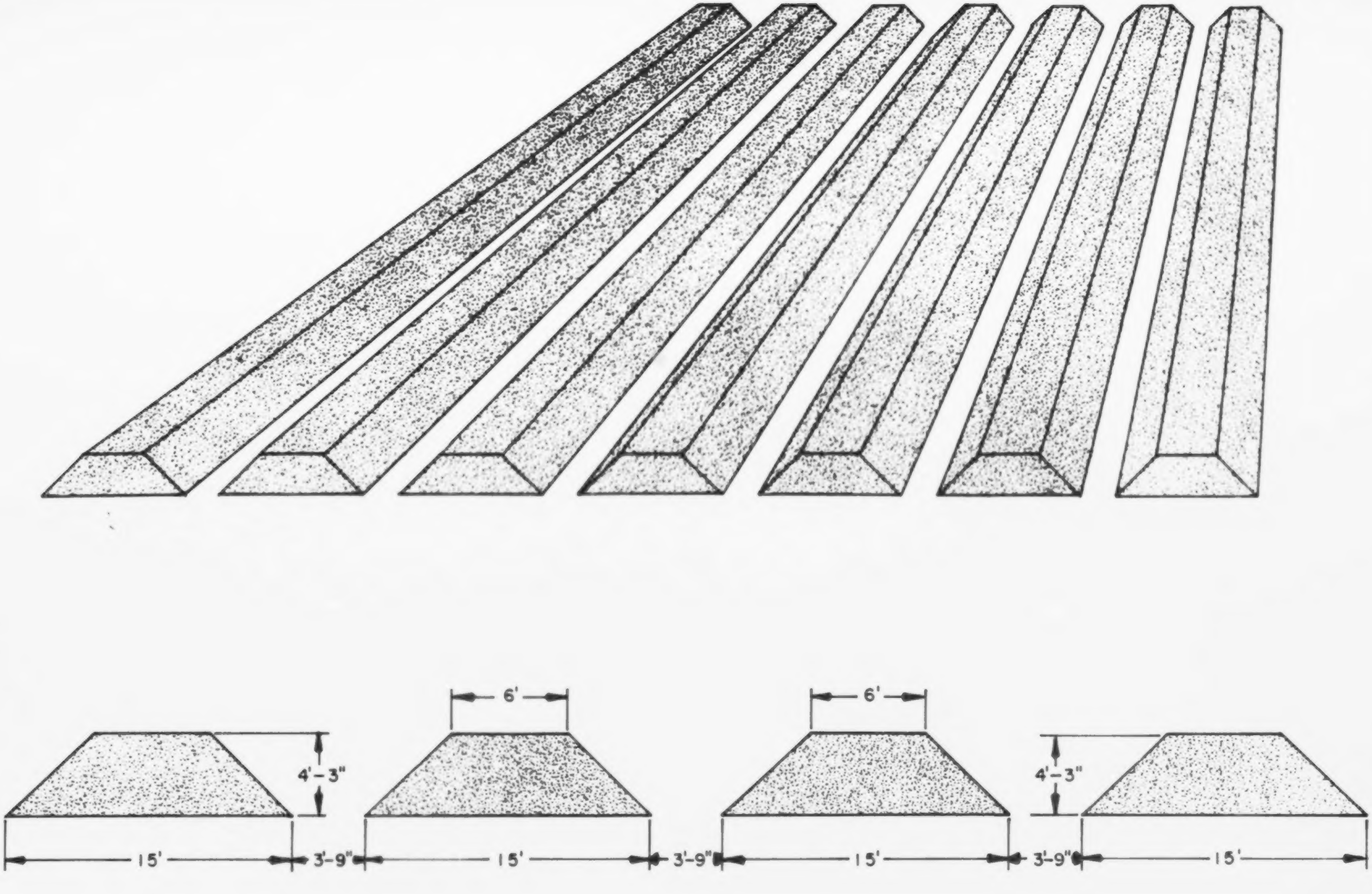

6'
6'
4'-3"
4'-3"
15'
3'-9"
15'
3'-9"
15'
3'-9"
15'

Fig 3.23 Windrow stack dimensions and spacing between stacks

Determine the moisture content of the dewatered sludge.

$$\text{Sludge Moisture, \%} = 100\% - \text{Dewaterd Sl Sol, \%}$$
$$= 100\% - 30\%$$
$$= 70\% \text{ moisture}$$

Calculate the pounds of compost that must be blended daily with the dewatered sludge to produce a mixture with 50 percent moisture content.

$$\text{Mixture Moisture, \%} = \frac{\text{Sludge, lbs/day} \times \text{Sl Moist, \%} + \text{Comp lbs/day} \times \text{C Moist, \%}}{\text{Sludge, lbs/day} + \text{Compost, lbs/day}}$$

Rearranging terms:

$$\text{Compost, lbs/day} = \frac{\text{Sludge, lbs/day} \times \text{Sl M, \%} - \text{Sludge, lbs/day} \times \text{Mix M, \%}}{\text{Mix M, \%} - \text{Comp M, \%}}$$
$$= \frac{4100 \text{ lbs/day} \times 70\% - 4100 \text{ lbs/day} \times 50\%}{50\% - 30\%}$$
$$= \frac{4100 \text{ lbs/day } (70\% - 50\%)}{50\% - 30\%}$$
$$= 4100 \text{ lbs/day}$$

EXAMPLE 41

Given: A 5 MGD plant produces 2700 lbs/day of dewatered digested secondary sludge. The dewatered sludge is at a concentration of 17 percent thickened sludge. Final compost product is at a moisture content of 30 percent.

Find: The total pounds of compost that must be recycled to produce an initial mixture moisture of 50%.

Solution:

Known		Unknown
Flow, MGD	= 5 MGD	Pounds per day of compost to produce an initial mixture of 50%.
Sludge, lbs/day (dewatered digested secondary sludge)	= 2700 lbs/day	
Dewatered Sludge, %	= 17% solids	
Final Compost, %	= 30% moisture	

Calculate the pounds per day of compost that must be recycled to produce an initial mixture moisture of 50 percent.

$$\text{Sludge Moisture, \%} = 100\% - \text{Dewatered Sl Sol, \%}$$
$$= 100\% - 17\%$$
$$= 83\%$$

$$\text{Compost, lbs/day} = \frac{\text{Sludge, lbs/day} \times \text{Sl M, \%} - \text{Sludge, lbs/day} \times \text{Mix M, \%}}{\text{Mix M, \%} - \text{Comp M, \%}}$$
$$= \frac{2700 \frac{\text{lbs}}{\text{day}} \times 83\% - 2700 \frac{\text{lbs}}{\text{day}} \times 50\%}{50\% - 30\%}$$
$$= 2700 \text{ lbs/day } \frac{(83\% - 50\%)}{(50\% - 30\%)}$$
$$= 4455 \text{ lbs/day}$$

The preceeding examples illustrate the effect the degree of sludge dewatering has on the quantity of compost that must be recycled to obtain the desired initial moisture content of the mixture. Even though fewer pounds of secondary sludge were produced (Example 41), more pounds of compost had to be recycled than for the primary sludge because of the differences in the degree of dewatering obtained.

The frequency of aeration or turning of the stacks is determined by trial and error. Obviously, the stacks should be turned frequently enough to prevent anaerobic conditions but not so frequently that excessive heat loss occurs. If the stacks are turned too often, excessive heat will be released and the temperature may drop to a point where it is unfavorable for the thermophilic composting bacteria. To optimize the frequency of turning requires close monitoring of the windrows for various turning frequencies. If the frequency of turning is not optimized as evidenced by anaerobic conditions or low temperatures, the time required to complete the process will increase.

GARDEN COMPOST FOR SALE

Climatic conditions play an important role in compost operations. Wet and cold climates generally require longer composting times than hot and arid regions. Wet weather is particularly damaging to windrow composting because the piles can become soaked and lose heat and the area generally becomes inaccessible to heavy equipment.

The desired final moisture content of compost product affects the time of composting because longer times are required for higher degrees of drying. In general, a well operated windrow compost facility can dry sludge from an initial moisture content of approximately 60 percent to a moisture content of 30 percent in about 15 to 20 days and to a final moisture of 20 percent in approximately 20 to 30 days. The final moisture content at which the compost process is stopped depends on whether the material is used as a fertilizer base, and/or the economics of hauling the compost to final disposal.

3.511 Normal Operating Procedure

The required steps for successful composting are generally the same from one operation to the next, although the mechanisms for blending sludge with bulking agents or compost material and the method of aeration might vary depending on the type of equipment used. The procedures for successful composting are listed below:

1. Dewater sludge to the highest degree economically practical.
2. Blend dewatered sludge with recycled compost or bulking agents to produce a homogeneous (even blended) mixture with a moisture of 45 to 65 percent.
3. Form the windrow piles and turn (aerate) once or twice daily for the first 4 to 5 days after windrow formation.

4. Turn the piles approximately once every two days to once a week to maintain temperatures (130 to 140°F or 55 to 60°C) and until the process is complete. The temperature of the piles should be routinely monitored during this period.
5. Load the compost onto trucks for disposal and/or recycle purposes.

3.512 Typical Performance

Typical performance and operational data for windrow composting operations are summarized in Table 3.23. Since climatic conditions play an important role in windrow composting, the data should be viewed with caution because it reflects summertime operation. During wet weather periods and in cold climates, the composting time may double or triple those presented in Table 3.23.

A higher ratio of blend material and longer compost times for secondary sludge are usually required because dewatered secondary sludges are commonly wetter than dewatered primary sludges. As a result, it is more difficult to produce a homogeneous blend when secondary sludges are composted.

TABLE 3.23 TYPICAL PERFORMANCE OF WINDROW COMPOSTING

Sludge Type[a]	Blend Material Ratio, (lb/lb)[b]	Initial Moisture, (%)	Max Compost Temp, (°F)[c]	Final Moisture, (%)	Compost Time, (days)
Primary	0.5:1 - 1:1	45 - 65	130 - 140	30 - 25	8 - 15
Secondary	1:1 - 1.5:1	45 - 65	130 - 140	30 - 25	15 - 25

[a] Sludge is digested and dewatered.

[b] Assuming compost product is used for blending. Ratio is lb Compost/lb Sludge or kg Compost/kg Sludge.

[c] (°F - 32) × 5/9 = °C.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 258 and 259.

3.50A What is the distinction between drying and incineration? What category does composting fall into and why?

3.51A Why does a suitable environment need to be established in compost piles?

3.51B Why are chemically stabilized and wet-oxidized sludges generally not composted?

3.51C List the criteria necessary to create a suitable compost environment.

3.51D List the factors that affect compost operations.

3.51E Explain why secondary sludges are not as easy to compost as primary sludges. Include a discussion of the "balling" phenomenon.

3.51F A medium-size wastewater treatment plant produces 4700 lbs/day of dewatered digested primary sludge with a solids concentration of 27 percent and 3300 lbs/day of dewatered secondary sludge with a solids concentration of 15 percent. The sludges are blended together and then composted in windrows. Determine the total pounds of compost that must be recycled and blended with the combined sludge to produce a moisture of 60 percent. The final compost product of the plant has a moisture content of 30 percent.

3.51G List the operational procedures required for windrow composting.

3.51H Why does the data presented in Table 3.23 indicate longer compost times for secondary sludge?

3.513 Troubleshooting

Windrow composting is a relatively simple and cost-effective method to further reduce and stabilize the sludge, but difficulties can arise which will render the process ineffective and troublesome. Barring climatic conditions, which the operator has no control over but should plan for, the most common problems that arise are anaerobic conditions and reductions in compost temperatures.

Anaerobic conditions can prevail if the initial moisture content is greater than the optimum range (45% to 65%), the stacks are not turned frequently enough, and/or balling occurs. If anaerobic conditions develop, the operator should increase the frequency of aeration and inspect the pile for balling. If balling is not evident and a uniform mixture exists, then more frequent turning should correct the problem. If balling is evident and a non-homogeneous mixture exists, increasing the frequency of turning may result in a decrease in the compost temperature. The operator should monitor the temperature and turn the stacks frequently enough to reduce the anaerobic odors while maintaining thermophilic temperatures.

As discussed earlier, balling will occur if the dewatered sludge is too wet and/or polymer over-dosing occur. The operator should optimize the performance of the dewatering facilities to eliminate future compost problems. If balling is not evident and piles are turned frequently, anaerobic conditions might develop if the moisture content of the stack is too high. This condition will usually result in corresponding reduced composting temperatures and can generally be traced back to not blending enough compost or bulking agents with the sludge prior to windrow formation. The stack will eventually recover from too much moisture but if the odors are severe, the operator might remix the stack with a sufficient quantity of bulking agents or compost to bring the windrow to a desirable moisture content.

Temperature decreases can be caused by high moisture contents or too much aeration or turning. If the pile is homogeneous and the moisture content is within the optimum range, the operator should reduce the frequency of turning to maintain thermophilic temperatures.

Table 3.24 summarizes usual operational problems and corrective measures that may alleviate or eliminate inefficiencies.

TABLE 3.24 TROUBLESHOOTING WINDROW COMPOSTING

Operational Problem	Possible Causes	Check or Monitor	Possible Solutions
1. Anaerobic conditions	1.a. Aeration frequency too low	1.a. Frequency of aeration and stack temperature	1.a. Increase aeration frequency
	b. Stack moisture too high	b. Stack moisture and temperature	b. Blend additional compost or bulking agents
	c. Balling	c. See 3	c. See 3
2. Low compost temperatures	2.a. Aeration frequency too high	2.a. Frequency of aeration and stack moisture	2.a. Decrease aeration frequency
	b. Stack moisture	b. Stack moisture	b. Blend additional compost or bulking agents
	c. Balling	c. See 3	c. See 3
3. Sludge balling	3.a. Dewatered sludge too wet	3.a. Dewatering facility	3.a. Increase cake dryness
	b. Polymer overdosing	b. Dewatering facility	b. Reduce polymer dosage
	c. Ineffective blending	c. Blending operation	c. Improve blending operations

3.52 Mechanical Drying

Mechanical heat drying is a dehydration process that removes water from sludge without combustion of the solid material. Mechanical drying is either direct or indirect. In an indirect drier, steam fills the outer shell of a rotating cylinder. Sludge circulates through the inner compartment and is dried by the heat from the steam. Direct driers use the direct contact of sludge with preheated gases.

The most common types of driers include direct and indirect rotary driers and modified multiple-hearth incinerators. Other mechanical driers include flash driers, atomized-spray driers, and fluidized-bed driers. Only the direct and indirect driers will be discussed here. Drying by modified multiple hearth incinerators will be discussed in Section 3.53 of this section.

Rotary driers or rotary kilns consist of a horizontal cylindrical steel shell with flights (mixing blades) projecting from the inside wall of the shell. A typical rotary drier is shown in Section 3.53, Figure 3.27. The basic difference between direct and indirect rotary driers is that indirect driers are equipped with a jacketed hollow through which steam is passed while hot gases are passed directly through the drier for direct drying.

In both cases, the dewatered sludge is blended with previously dried material and continuously fed into the drier. The cylindrical drum rotates about 5 to 8 rpm and the inlet end is slightly higher than the discharge end. As the drier rotates, the flights projecting from the shell wall elevate, tumble, and mix the material (like a clothes drier) to provide frequent contact by tumbling the wetted sludge. The rotation of the drier drum causes the sludge to fall off the walls of the drum near the top or crown portion of the kiln. As the sludge falls it becomes drier and is conveyed towards the outlet end of the drum. Also, the speed of rotation of the drum will affect the moisture content of the sludge being dried.

Blending of the sludge with dried product is generally practiced to improve the conveying characteristics of the sludge and to reduce the potential for balling. This blending of wet sludge with a previously dried sludge is accomplished in a *PUG MILL*.[39] As is the case with compost operations, the sludge may clump together and form balls that readily dry on the outer surface but remain wet on the inside if the blending is not done properly.

3.520 Factors Affecting Mechanical Drying

The degree of drying obtained and the efficiency of rotary driers depend on: (1) sludge type, (2) sludge detention within the drier, (3) temperature, and (4) moisture content and ratio of wet-to-dry sludge before being fed to the rotating kiln.

---

[39] *Pug Mill. A mechanical device with rotating paddles or blades that is used to mix and blend different materials together.*

Secondary sludges have a greater tendency to ball and contain more water than primary sludges. Secondary sludges are, therefore, not as well suited to mechanical drying operations as primary sludges. Obviously, any sludge should be dewatered to the highest degree possible by centrifuges, filter presses, or vacuum filters to reduce the volume of water delivered to the drier and to facilitate the drying process.

The length of time the sludge remains in the drier and the temperature of the drying gas will affect the degree of drying obtained. As drying time and temperature increase, the moisture content of the dried product will decrease. Drying time is governed by the size of the drier, the quantity of sludge applied and the speed of the drum. As the speed increases, the drying time decreases because the sludge is picked up and tumbled towards the outlet at a faster rate. To increase the drying time, the operator should lower the drum speed and/or reduce the quantity of sludge applied, if possible. The operator should be aware that as the drum speed is reduced to increase the drying time, the frequency of contact between wetted sludge particles and the drying medium will also decrease.

A fine line exists between operating the drum at a speed to maximize drying time while still providing frequent contact between wet sludge particles and hot gases or heated surfaces. Trial and error procedures should afford the operator the best opportunity to maximize the drum speed.

3.521 Normal Operation and Performance

Operational data on heat driers is scarce since the process is not routinely used at the present time. The use of mechanical driers is uncommon because this is a very expensive process principally due to large energy demands.

Due to this relative lack of operating data, it is virtually impossible to list typical performance and operating data or to outline specific operational procedures. In general, the sludge to be dried should be dewatered to the highest degree possible, blended with previously dried material to produce a homogeneous structure and adequately mixed or tumbled within the drier to maximize contact with the drying medium (gases or heated surfaces) and to minimize sludge balling.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 259.

3.52A Distinguish between direct and indirect drying.

3.52B Would the multiple-hearth furnace be categorized as a direct or indirect drier? Why?

3.52C What purpose do the flights installed on rotary driers serve?

3.52D Why is sludge blended with previously dried material prior to rotary drying?

3.52E Why should sludge be dewatered to its maximum degree prior to mechanical drying or incineration?

3.52F What affect does drum speed have on rotary drier performance?

3.53 **Sludge Incineration** by Richard Best

3.530 Process Description

Sludge incineration is defined as the conversion of dewatered cake by combustion to ash, carbon dioxide, and water vapor. As a result of incineration, the volume of sludge is significantly reduced (up to 90 percent by weight). This reduction in volume is caused by the evaporation of the water in the cake and the conversion of the volatile matter in the cake to carbon dioxide and water. The only material remaining after the incineration of a cake is some ash and the inert matter in the cake.

The most common type of sludge incinerator is the multiple-hearth furnace (MHF) (Fig. 3.24) and will be the only process discussed in detail in this section. Other incineration designs include fluidized-bed reactors (Figs. 3.25 and 3.26) and rotary kilns (Fig. 3.27).

Rotary kilns may be used to either dry or incinerate sludge. They also have been used for refuse incineration and ore processing. In Figure 3.27 a storage bin is located on the lower left to hold the sludge for processing. The clam shell bucket loads the sludge into the feed hopper. A conveyor moves the sludge to the inlet hopper to the rotary kiln. Inside the kiln the sludge is either dried or incinerated. Dried sludge or ash is removed from the kiln into the hopper in front of the operator.

Hot gases flow through the scrubber on the right to remove the particulate matter suspended in the gases. The stack in the middle right serves as an emergency bypass stack in case of system failure. Behind the stack is a clarifier that is used for ash separation in liquid ash systems.

The MHF, in its simplest form, is a refractory-lined (high temperature endurance bricks) steel cylinder equipped with a centralized shaft and runners (Fig. 3.24). Inside the MHF there are a number of levels called hearths. A center shaft passes through the center of the hearths. Arms are attached to this center shaft. Plows are attached to each arm which are called rabble teeth. The hearths are "sprung" arches and are not connected to the center shaft.

During incineration, sludge cake enters the top of the furnace and is moved back and forth across the hearths by the rabble teeth. The cake drops alternatingly on each hearth through an outer drop opening and then through a center drop and works its way down through the hearths. As the cake reaches the edge of one hearth it drops to the hearth below until it reaches ignition temperature and burns. Ash remaining after the sludge is burned is then rabbled (moved across the hearths) until it reaches the bottom of the MHF and has been cooled.

3.531 Furnace Description

Before attempting to understand the operation of an MHF, the purpose of the various parts of the furnace must be understood.

3.5310 Furnace Refractory. The furnace shell is insulated to prevent the loss of heat into the atmosphere and to protect the equipment and workers from the high temperatures found within the furnace. The outer steel shell is protected from the internal heat by 9 to 13 inches (23 to 33 cm) of refractory (brick resistant to high temperature) on the inside.

The hearths or levels within the furnace are actually self-supported arches. The weight of the arches or the thrust is transmitted to the outside shell. The hearths are made of a specially shaped refractory brick with castable insulation poured into the odd-shaped spaces.

Figures 3.28 and 3.29 illustrate the two different types of hearths installed within the MHF. The hearths on which the cake drops to the next lower hearth from the center are called "in" hearths. The hearths on which the cake drops through holes on the outside of the furnace are called "out" hearths.

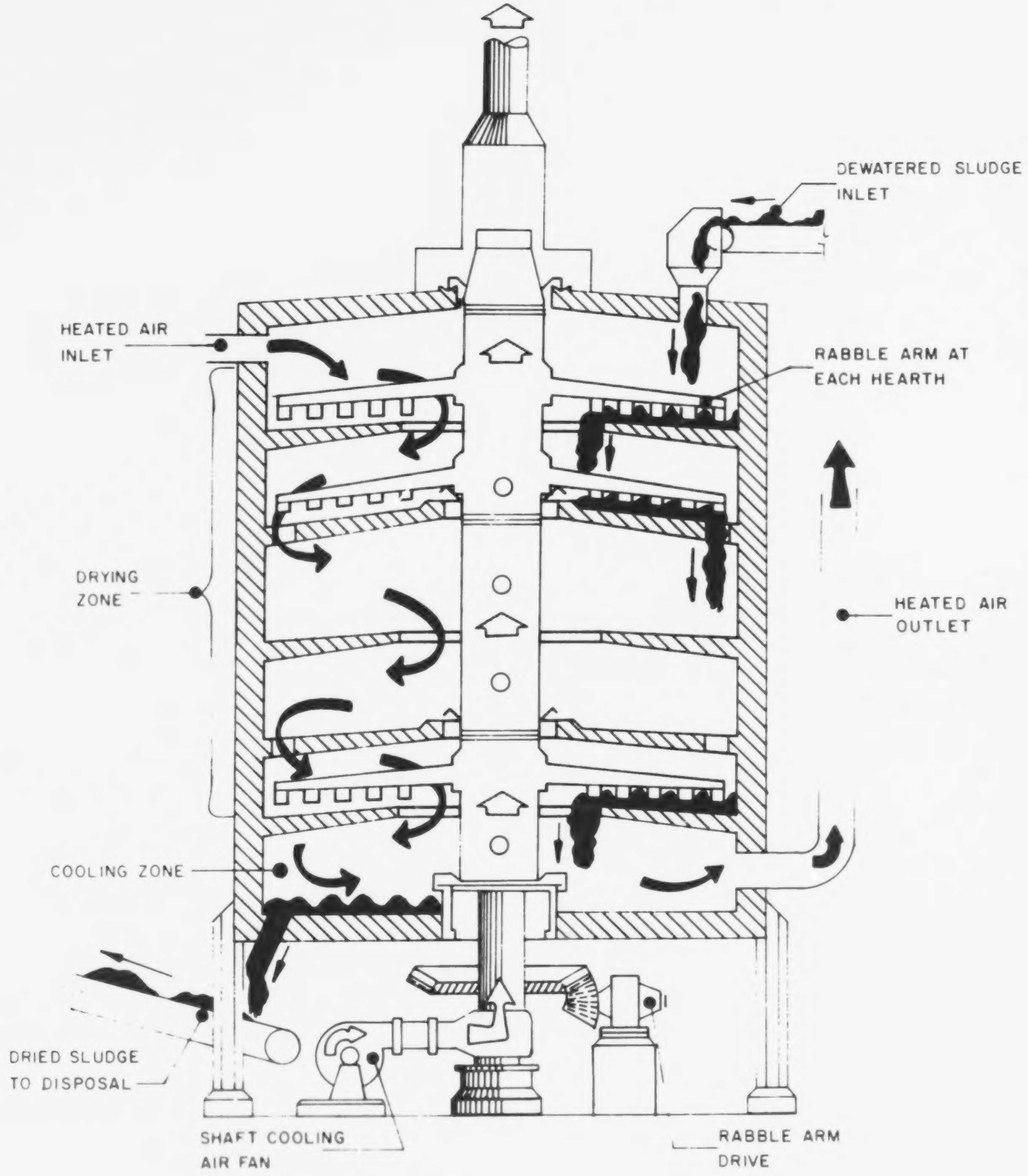

DEWATERED SLUDGE INLET
HEATED AIR INLET
RABBLE ARM AT EACH HEARTH
DRYING ZONE
HEATED AIR OUTLET
COOLING ZONE
DRIED SLUDGE TO DISPOSAL
SHAFT COOLING AIR FAN
RABBLE ARM DRIVE

Fig. 3.24 Multiple-hearth furnace used as a sludge dryer

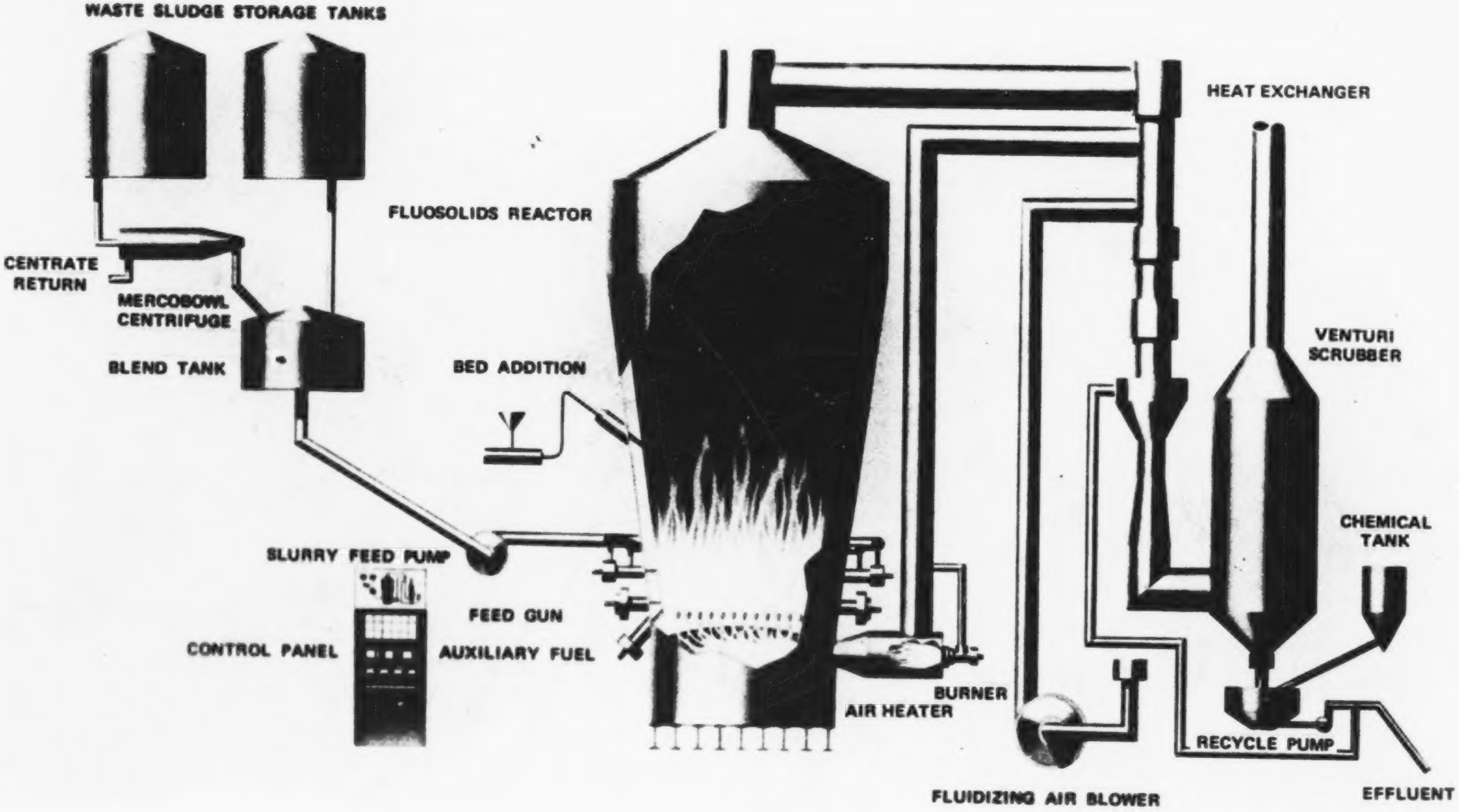

WASTE SLUDGE STORAGE TANKS
CENTRATE RETURN
MERCOBOWL CENTRIFUGE
BLEND TANK
FLUOSOLIDS REACTOR
BED ADDITION
SLURRY FEED PUMP
CONTROL PANEL
FEED GUN
AUXILIARY FUEL
BURNER
AIR HEATER
HEAT EXCHANGER
VENTURI SCRUBBER
CHEMICAL TANK
FLUIDIZING AIR BLOWER
RECYCLE PUMP
EFFLUENT

Fig. 3.25 Fluidized-bed reactor system

(Permission of Dorr-Oliver Incorporated)

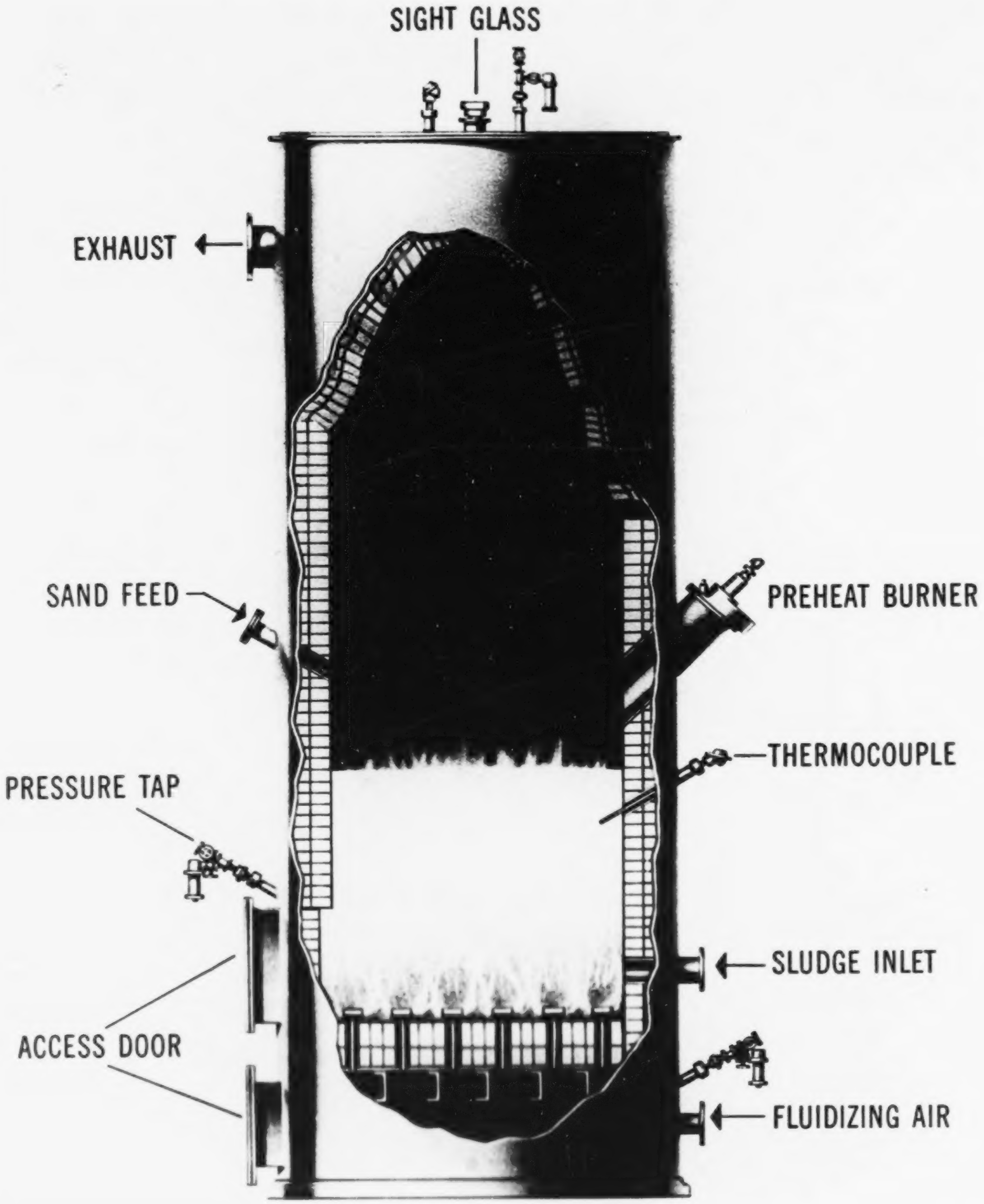

SIGHT GLASS
EXHAUST
SAND FEED
PREHEAT BURNER
THERMOCOUPLE
PRESSURE TAP
SLUDGE INLET
ACCESS DOOR
FLUIDIZING AIR

Fig. 3.26 Fluidized-bed reactor

(Permission of Dorr-Oliver Incorporated)

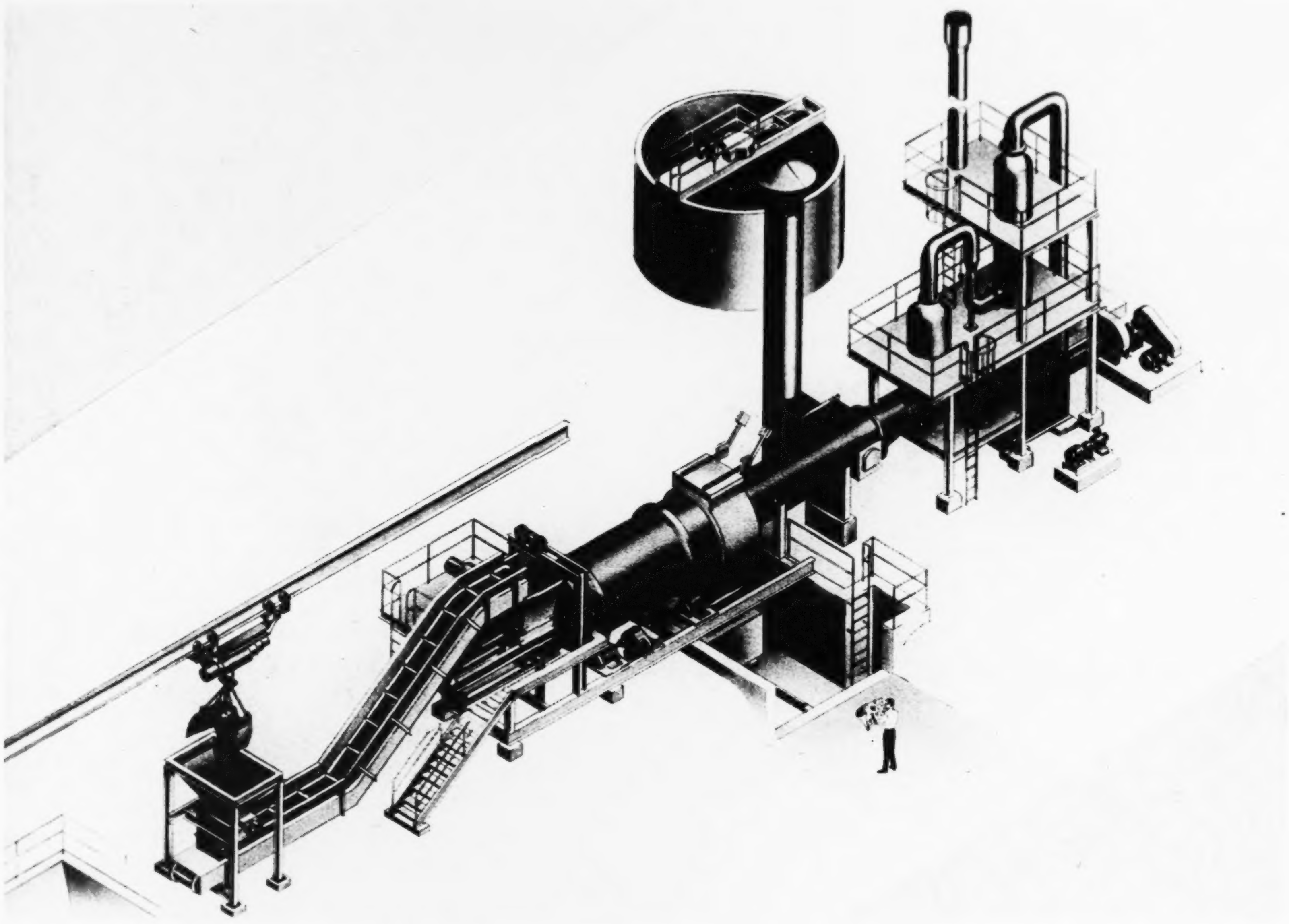


Fig. 3.27 Rotary kiln

(Permission of Envirotech)

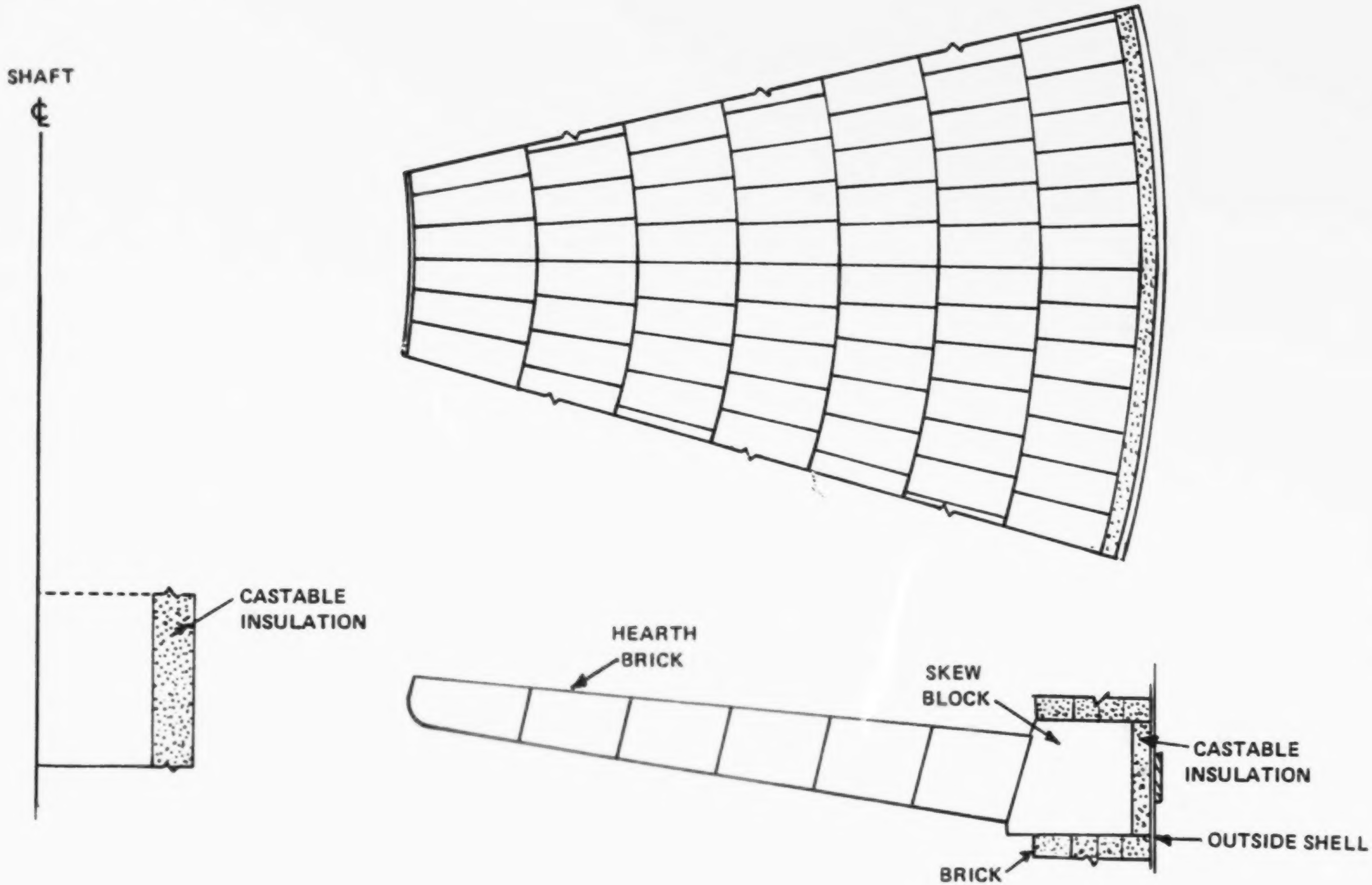

SHAFT
℄
CASTABLE
INSULATION
HEARTH
BRICK
SKEW
BLOCK
CASTABLE
INSULATION
OUTSIDE SHELL
BRICK

Fig. 3.28 In hearth

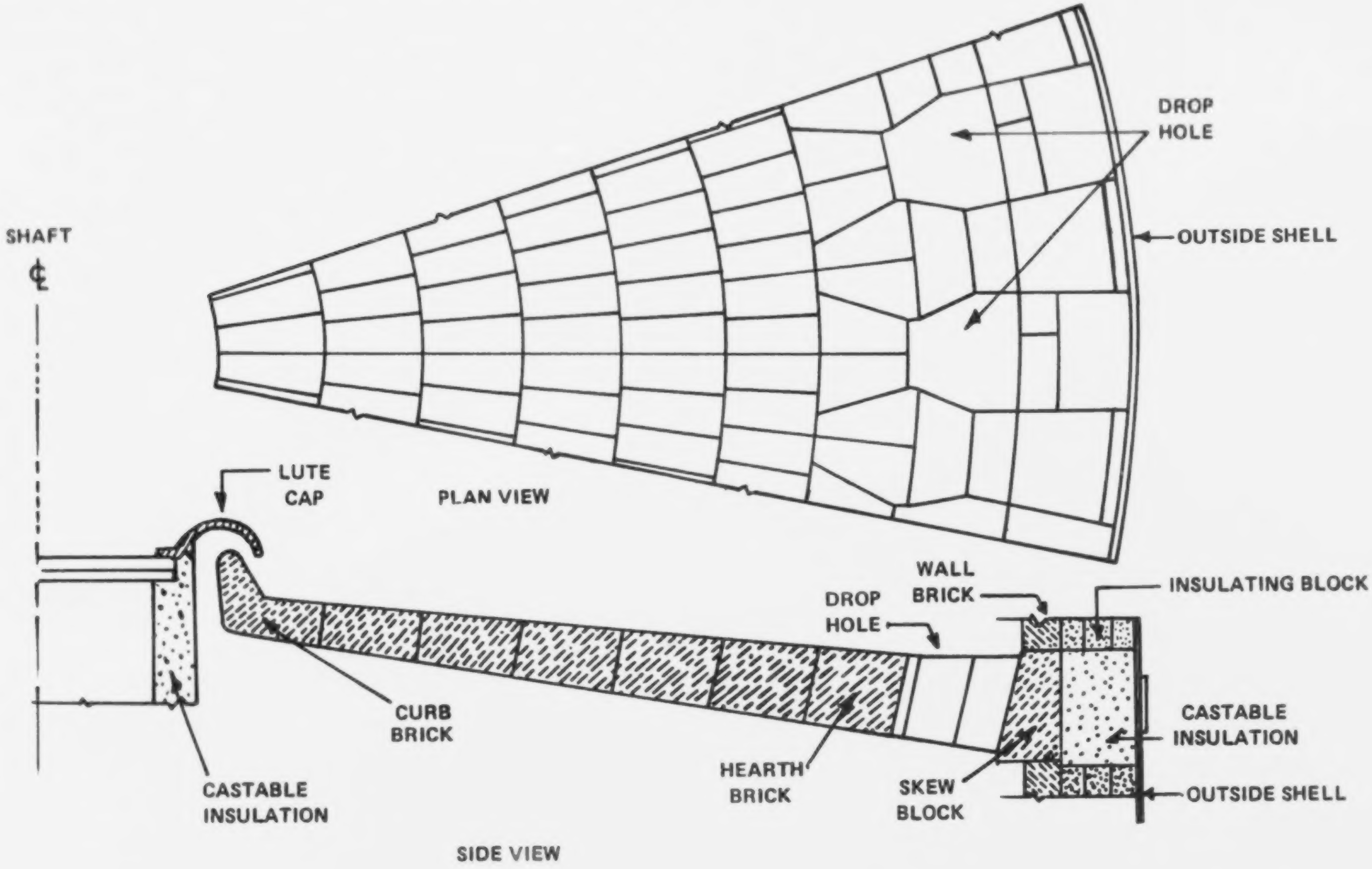

DROP HOLE
OUTSIDE SHELL
SHAFT
℄
LUTE CAP
PLAN VIEW
WALL BRICK
INSULATING BLOCK
DROP HOLE
CURB BRICK
HEARTH BRICK
SKEW BLOCK
CASTABLE INSULATION
OUTSIDE SHELL
CASTABLE INSULATION
SIDE VIEW

Fig. 3.29 Out hearth

Out hearths (those hearths where the cake moves to the outside edge of the hearth) have a circular cap ringing the center shaft at the hearth/shaft meeting point. This is known as the lute cap (Fig. 3.30). The purpose of this cap is to prevent air and sludge from passing through the shaft opening rather than through the drop holes.

The holes around the outside of the hearth are called "drop holes." The sludge cake passes to the next lower or in hearth (those hearths where the waste material moves toward the inside of the furnace) through these drop holes.

When the furnace is in operation, cake enters the furnace through a counterbalanced flap gate installed to prevent the escape of gasses from the furnace and to limit the flow of cold air into the top of the furnace.

Once the cake goes through the flap gate, it drops onto the top hearth of the furnace. This is called "hearth No. 1." At this point, the cake begins to be moved through the furnace by action of the rabble teeth (Figure 3.30). This process is called "rabbling."

Rabbling is a term used to describe the process of moving or plowing the material inside a furnace by using the center shaft and rabble arms. Rabbling forms spiral ridges of cake on each hearth which aids with the drying and burning of the cake. The surface area of these ridges varies with the side slope of the cake (or the slope of the sides of the furrows). This angle may vary widely from 20 degrees up to 60 degrees. Rabbling, in addition to exposing the wet sludge cake surface to the furnace gases, helps to break up large cake particles which increases the surface area of the sludge available for drying.

Because of the ridges formed by rabbling, the surface area of cake exposed to the hot gases is considerably greater than the hearth area provided. During rabbling the cake falls through the in hearth and the out hearth ports and the counter-current flow of hot gases over the cake decreases the drying time.

3.5311 Center Shaft. The rotating shaft to which the rabble arms and teeth are attached is called the "center shaft." The center shaft has seals at the top and bottom called "sand seals" (Fig. 3.31). These are stationary cups partially filled with sand that surround the shaft. A cylindrical steel ring is attached to the shaft and extends down into the sand to form the seal. At the bottom of the shaft, the sand cup is attached to the shaft and rotates while the steel ring is fixed to the furnace bottom. These seals are very effective if properly maintained. They prevent the escape of heat and gases from the furnace and the entrance of air at these points. Gases escaping from the furnace could cause potential air pollution problems. Unplanned entrance of air can cause draft changes and false furnace conditions which will reflect on the control panel instruments. These seals also allow for the differential expansion and contraction of the furnace body due to changes in temperature.

Due to the extremely high temperatures within the MHF, the center shaft and the rabble arms are hollow. This allows a fan, installed at the bottom of the furnace, to blow cool air (ambient air) through the center shaft and rabble arms while the furnace is in operation (Figures 3.30 and 3.32). This fan is called the cooling air fan. The hot air exhausted at the top of the furnace from the shaft is called cooling air.

Depending on the furnace design, the cooling air can either be returned to the burning zone of the MHF or vented to the atmosphere.

3.5312 Shaft Drive. The center-shaft drive mechanism on an MHF is usually a combination of an electric variable-speed drive and an independent gear reducer. Occasionally hydraulic drives are used instead of electric variable-speed drives. Connected to the output shaft of the gear reducer is a pinion gear which drives the large bevel or bell gear attached to the bottom of the furnace shaft.

3.5313 Top and Lower Bearing. Each MHF manufacturer uses its own bearing design for the top and lower shaft bearings. The operational principles are the same for all manufacturers.

The lower bearing supports the entire weight of the center shaft. In a larger furnace this could be 60,000 pounds (27,240 kg) or more. The top bearing maintains shaft alignment. The shaft rotates within the bearing and the bearing housing maintains alignment.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 259.

3.53A What is sludge incineration?

3.53B What is the refractory?

3.53C What are rabble arms and rabble teeth?

3.53D The lute cap serves what purpose?

3.53E What is the purpose of the sand seal?

3.5314 Furnace Off-Gas System (Fig. 3.33). As the sludge cake is incinerated, hot air and gases must be vented from the MHF. To vent these gases, almost all incinerators are equipped with an emergency by-pass damper located on the top of the MHF. The function of the by-pass damper is to vent the furnace gases to the atmosphere during emergency conditions. This device protects equipment and operating personnel.

CYCLONE SEPARATOR. Under normal operation of the MHF, the furnace gases are vented into the off-gas system. As the gases leave the furnace, the first unit that the gases may enter is the cyclone separator.

Hot furnace gases which have fly ash and solid particles in suspension are drawn through the furnace into the cyclone by the induction draft (I.D.) fan. The cyclone is constructed so that the gas flow sets up a separating current. This current causes the fly ash and heavy particles to settle out into the cyclone bin at the bottom. The cyclone bin has a flap gate which dumps the ash into the recycle screw. The recycle screw returns the fly ash and heavy particles to the furnace on a middle hearth. This material is then carried out with the ash. A vibrator assists in keeping the fly ash and particles moving downward in the cyclone bin. The hot gas and finer particles are drawn up out of the cyclone and move on to the precooler.

PRECOOLER. The precooler is a section of furnace exhaust ducting in which water is sprayed to cool the furnace exhaust gases to saturation temperature and to wet the small particles of light ash (particulate matter). The precooler lowers the temperature of the exhaust to a point where it prevents damage to the rest of the off-gas system components.

VENTURI SCRUBBER. Immediately below the precooler is a constant or variable throat Venturi scrubber. The Venturi scrubber is provided to clean the particulate matter from the cooled furnace gases. Water is sprayed into the top of the Venturi for even distribution.

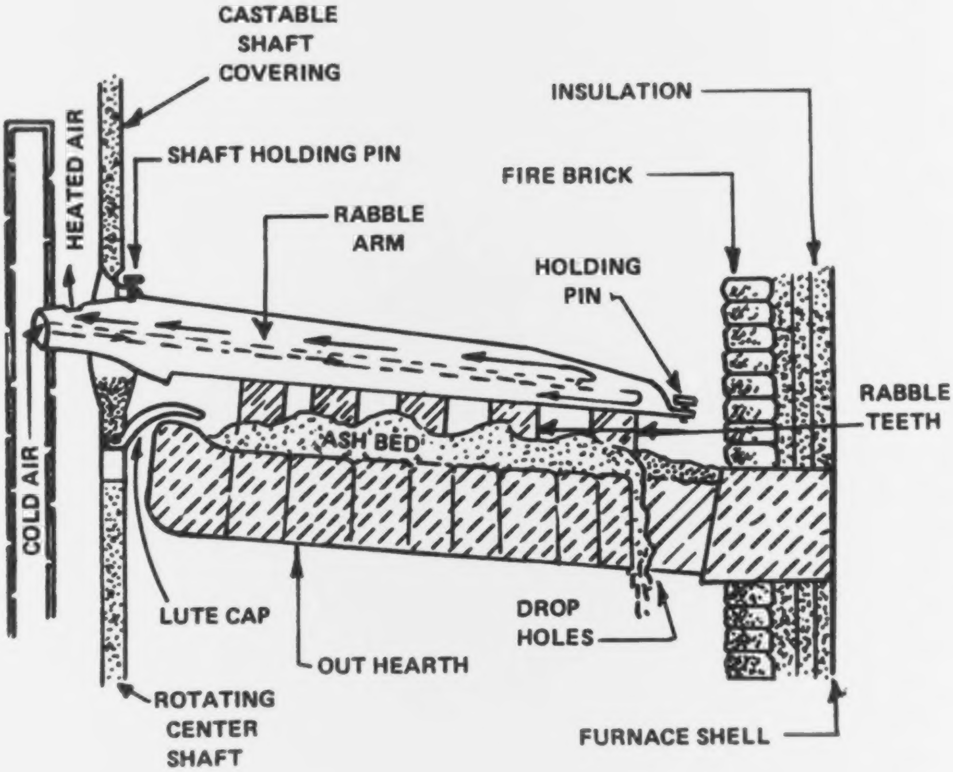

CASTABLE SHAFT COVERING
INSULATION
SHAFT HOLDING PIN
FIRE BRICK
HEATED AIR
RABBLE ARM
HOLDING PIN
RABBLE TEETH
ASH BED
COLD AIR
LUTE CAP
DROP HOLES
OUT HEARTH
ROTATING CENTER SHAFT
FURNACE SHELL

Fig. 3.30 Action of rabble arm and rabble teeth

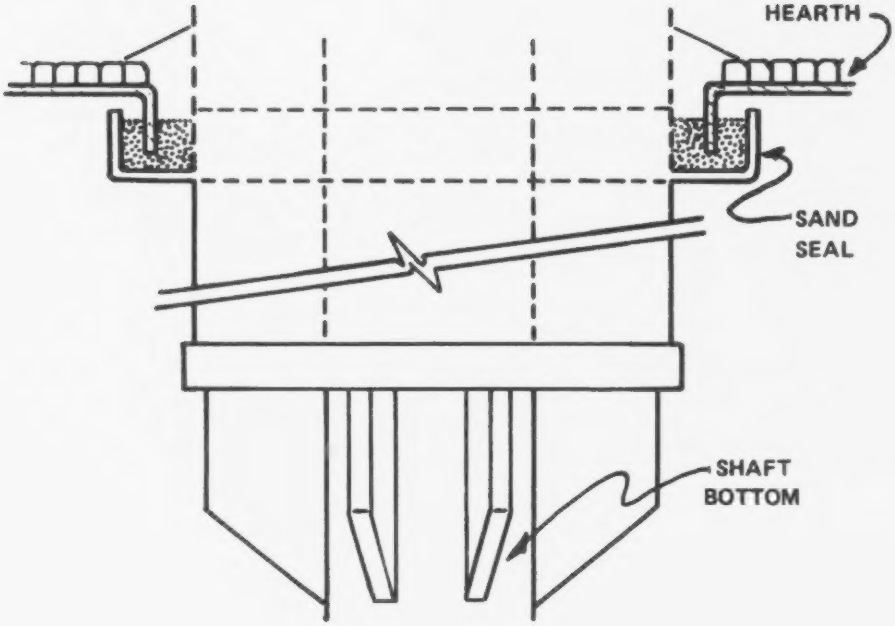

HEARTH
SAND SEAL
SHAFT BOTTOM

Fig. 3.31 Lower sand seal schematic

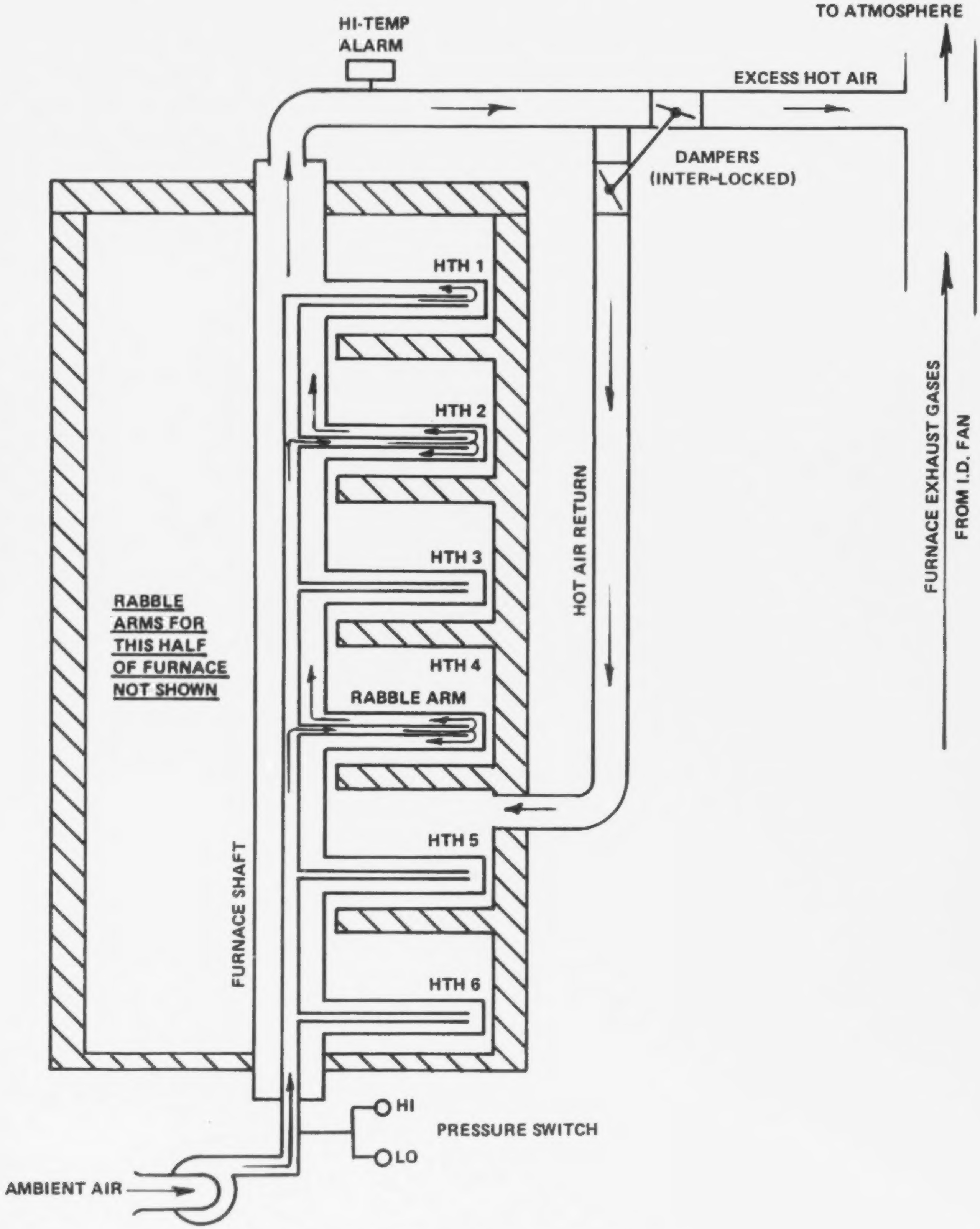

TO ATMOSPHERE
HI-TEMP ALARM
EXCESS HOT AIR
DAMPERS (INTER-LOCKED)
HTH 1
HTH 2
FURNACE EXHAUST GASES FROM I.D. FAN
HOT AIR RETURN
HTH 3
RABBLE ARMS FOR THIS HALF OF FURNACE NOT SHOWN
HTH 4
RABBLE ARM
HTH 5
FURNACE SHAFT
HTH 6
HI
PRESSURE SWITCH
LO
AMBIENT AIR

Fig. 3.32 Shaft cooling air system for a six-hearth furnace

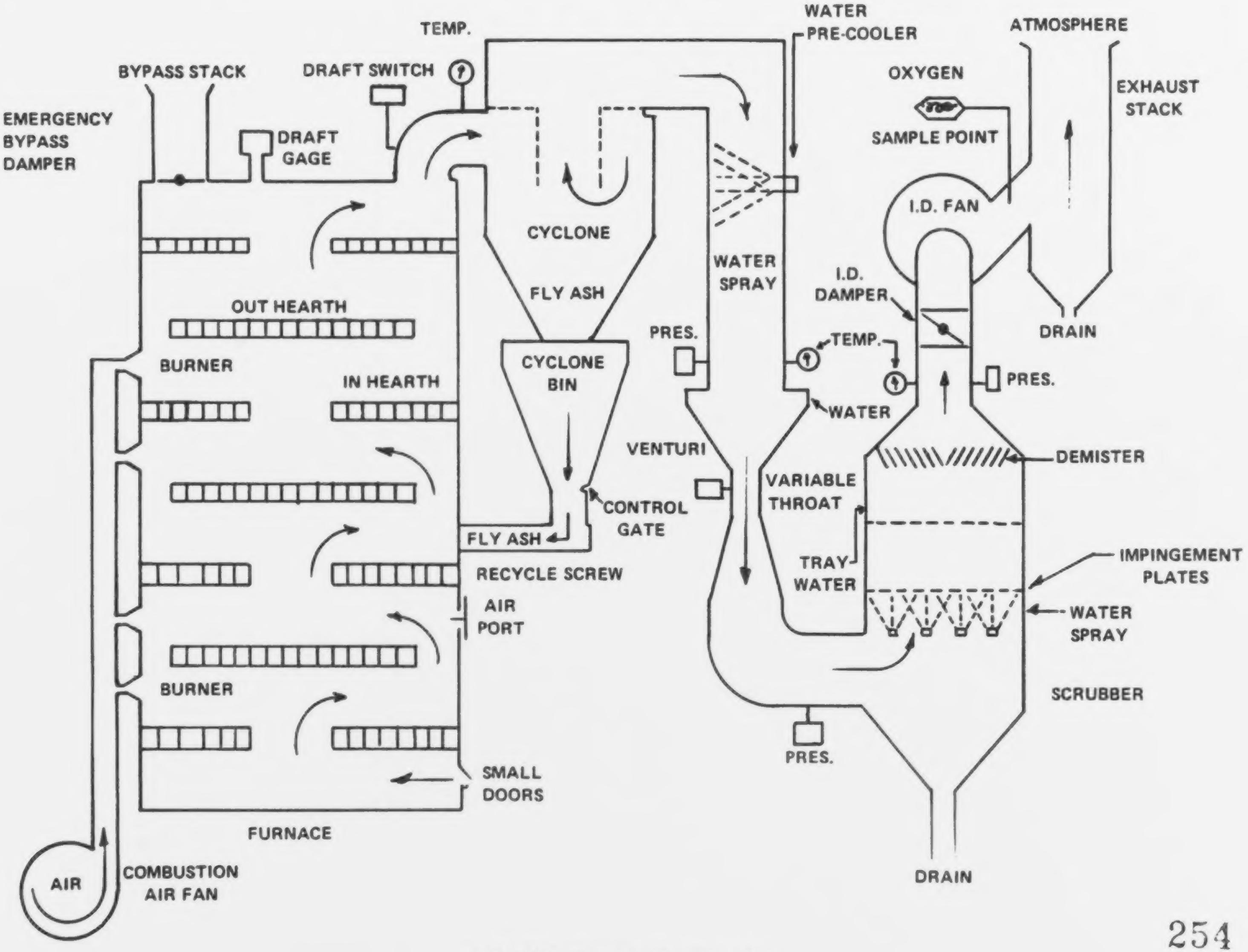

TEMP.
WATER
PRE-COOLER
ATMOSPHERE
BYPASS STACK
DRAFT SWITCH
OXYGEN
EXHAUST
STACK
EMERGENCY
BYPASS
DAMPER
DRAFT
GAGE
SAMPLE POINT
I.D. FAN
CYCLONE
WATER
SPRAY
I.D.
DAMPER
OUT HEARTH
FLY ASH
DRAIN
PRES.
TEMP.
CYCLONE
BIN
BURNER
IN HEARTH
PRES.
WATER
VENTURI
DEMISTER
VARIABLE
THROAT
CONTROL
GATE
FLY ASH
TRAY
WATER
IMPINGEMENT
PLATES
RECYCLE SCREW
AIR
PORT
WATER
SPRAY
BURNER
SCRUBBER
PRES.
SMALL
DOORS
FURNACE
DRAIN
AIR
COMBUSTION
AIR FAN

Fig. 3.33 Furnace off-gas system

The water and gases are mixed and accelerated in an adjustable, narrow Venturi throat. As the gases re-expand in the exit portion of the Venturi, the water is split into tiny droplets in which the particulate matter is entrapped and removed from the gas stream.

The ducting directly below the Venturi scrubber usually makes a sharp bend. Because of the high air speed, the water droplets with their collected particulate matter cannot make the turn and run into the bottom of the ducting. From there, the water and particulate matter flow to a drain. Following the Venturi scrubber there is usually an impingement scrubber.

IMPINGEMENT SCRUBBER (Fig. 3.34). The impingement scrubber consists of three sections:

1. The impingement baffles,
2. The lower sprays, and
3. The mist eliminator.

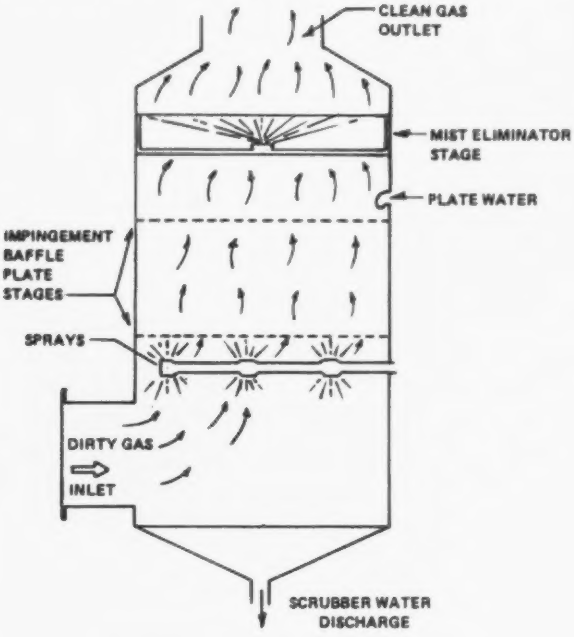


Fig. 3.34 Impingement scrubber

The impingement plates are level, flat stainless steel plates with thousands of tiny holes in them. The gas is drawn up through the perforated impingement plates which have water continually flowing across them. As the gas passes through the holes, it collects water droplets while leaving any remaining particles trapped in the flowing water due to impingement action of the bars just above the perforations. The particle and water slurry overflows the plates, is collected in the bottom of the scrubber and is drained out. The gas carrying water droplets is drawn up into the mist eliminator.

The fixed-bladed mist eliminator directs the gas stream to the side of the scrubber shell where the droplets collect by centrifugal action. The collected droplets drain back down to the impingement plate section for reuse. The remaining cool, clean gas is drawn out the top of the scrubber by the induced draft (I.D.) fan.

INDUCED DRAFT (I.D.) FAN AND DAMPER. The I.D. fan provides the suction or draft necessary to vent the furnace gases and pull them through the off-gas system. Since the quantity of these gases varies with the quantity and type of cake burned in the MHF, a damper is installed immediately before the I.D. fan. This damper is used to regulate the suction or draft within the MHF.

ASH HANDLING SYSTEM. Ash is the inorganic material left after the sludge cake is burned. This material is disposed of in a variety of methods depending on the MHF installation. The two most common are wet and dry ash systems which we will discuss briefly. Other types of ash systems include pneumatic ash transport, ash classification and ash eductors.

The wet ash system is the simplest of all ash handling systems. The ash drops out of the MHF into a mix tank where effluent water is continuously added. This produces an ash slurry which is pumped to an ash lagoon. The ash settles out in the lagoon and the water is returned to the front end for treatment. The ash is left to dry and ultimately removed from the lagoon for disposal.

In the dry ash system, the ash drops from the MHF onto an ash screw conveyor. This screw conveyor carries the ash to a bucket elevator. The bucket elevator transports the ash to a storage bin where it awaits disposal.

At the bottom of the storage bin is the ash conditioner. This is a screw conveyor equipped with a series of water sprays. The water sprays wet the ash so it does not create dust or blow off a truck during transport.

3.5315 Burner System. Burners are provided on an MHF to supply the necessary heat to ignite the sludge. Prior to discussing the burner system, it is important to understand combustion. In order for any combustion to occur, the three ingredients of the fire triangle (Figure 3.35) must be present.

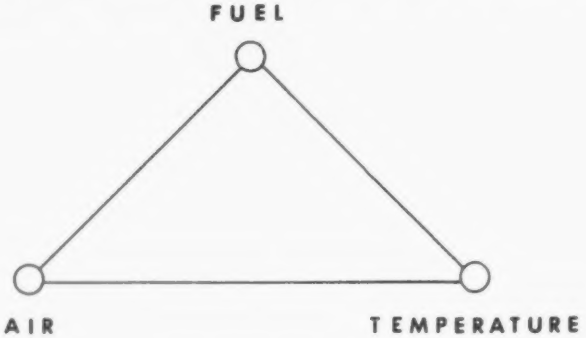


Fig. 3.35 Fire triangle

For complete combustion to occur, there must be a specific ratio between the amount of fuel and the amount of air. The burner system described here is manufactured by the North American Manufacturing Company. This type of system is common to all burner systems supplied on MHF's although component names may be different.

COMBUSTION AIR FAN. This fan supplies the filtered burner/combustion air for the burner system.

OIL PUMPS. Positive displacement pumps supply oil to the burners (except for natural gas burners).

SAFETY VALVES. Electric solenoid valves are used to stop the fuel flow during a burner shutdown.

PRESSURE REGULATORS. Standard pressure regulators are used to control the fuel pressure.

AIR-FUEL RATIO REGULATOR. A pressure regulator that maintains a specific ratio between fuel and air.

COMBUSTION-AIR CONTROL VALVE. A butterfly valve that governs the flow of combustion air to the burner.

FLOW-LIMITING VALVE. A metering valve that allows a specific flow of combustion air to the burner.

FUEL. MHF burners are fired by a variety of fuels. Natural gas, number 2 fuel oil, and heavy oil. The fuel and air are regulated to the proper pressure and injected into the burner. At this point the fuel/air mixture is ignited by the pilot and the resulting flame is sensed by the ultra-violet scanner which signals the burner control station that a flame-safe condition exists.

The temperature and firing rate of the burner is then controlled by the temperature indicator controller (T.I.C.).

3.532 Controls and Instrumentation

Usually, multiple hearth furnaces are equipped with the following controls to maintain temperature, draft, and oxygen.

LOW DRAFT SWITCH. This switch shuts down the MHF in the event of an unsafe draft condition.

DRAFT CONTROLLER/INDICATOR. This is a controller that opens and closes the induced draft damper in order to maintain the draft within the MHF.

OXYGEN ANALYZER/CONTROLLER. This instrument measures the percent oxygen in the stack gas which is an indication of complete combustion. In some cases a controller is attached to this instrument to control the oxygen level in the furnace by regulating the combustion air.

TEMPERATURE INDICATOR CONTROLLER (T.I.C.). This instrument controls the burner firing rate and the hearth temperature.

TEMPERATURE RECORDING CHART. A strip recorder used to record the temperatures throughout the furnace.

SCRUBBER DIFFERENTIAL-PRESSURE INDICATOR. An instrument which indicates the pressure difference across the scrubber. This pressure difference is the main operating variable on the Venturi scrubbers.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 259.

3.53F List the parts of the furnace off-gas system and the purpose of each part.

3.53G Why do multiple-hearth furnaces contain burners?

3.53H What three ingredients are necessary for combustion to occur?

3.533 MHF Operations

Operation of an MHF requires a person knowledgeable enough in furnace theory and operations to keep the fire burning in the desired location and prevent damage to the equipment. But more important, a furnace operator must be able to look at the instruments, fire, and feed and be able to predict what is going to happen. The operator makes the necessary changes to maintain a stable burn and the most efficient burn possible. The objective of an operator is to operate the furnace at design conditions and to keep operating costs to an absolute minimum.

3.5330 Furnace Zones. The furnace is generally considered to be separated into three distinct zones, drying, combustion, and cooling. None of these zones are confined to any specific hearth or hearths, but will always be in this order. The area of each zone is determined by actual conditions in the furnace.

The furnace zones are as follows:

1. *THE DRYING ZONE.* In this area, generally the top one-fourth of the furnace, the sludge is exposed to high temperatures while being continuously turned over by the rabble teeth. The constant turning over of the sludge exposes more surface area to the high temperature gases flowing over the cake surface and increases the rate at which moisture is driven out of the wet sludge. The wetter the cake entering the furnace and the greater the feed rate, the more hearths will be in the drying zone.
2. *THE COMBUSTION ZONE.* Ideally this zone is where the actual burning of the volatile materials in the sludge takes place. Usually the combustion zone will be confined to only one hearth. Ideally, the actual burning should occur approximately at the midpoint of an out hearth (Figure 3.36). At this location, all gases given off in the final stages of the drying process, just prior to ignition, will be destroyed. This happens since they must pass through the flame, with very high temperatures, as the flame goes through the drop hole around the shaft.
3. *THE COOLING ZONE OR AIR PREHEAT ZONE* is where the ash is cooled. Any remaining carbon in the sludge is burned off here before the ash falls into the ash hopper. At the same time as the ash passes down the furnace, the air admitted through the air ports, slide doors or shaft return-air duct is flowing over the hot ash and being preheated.

3.5331 Auxiliary Fuel. The amount of fuel used will depend on several factors:

1. Conditions in the furnace.

   Items such as shaft speed, number of slide doors, air ports open, or forced air ducted to the furnace, and the amount of shaft cooling air being returned to the furnace influence conditions in the furnace.

   Air for proper combustion should be added low in the furnace. This allows the cool ambient air to pick up a great amount of heat as it passes across the hot ash and also cools the ash before disposal.

If air is added in the fire zone or above it, incoming air will be much cooler and will serve to cool the air where it enters the furnace. This will cause more fuel consumption. Air should be added at or above the fire *ONLY* when absolutely necessary to reduce the temperature or quench the fire.

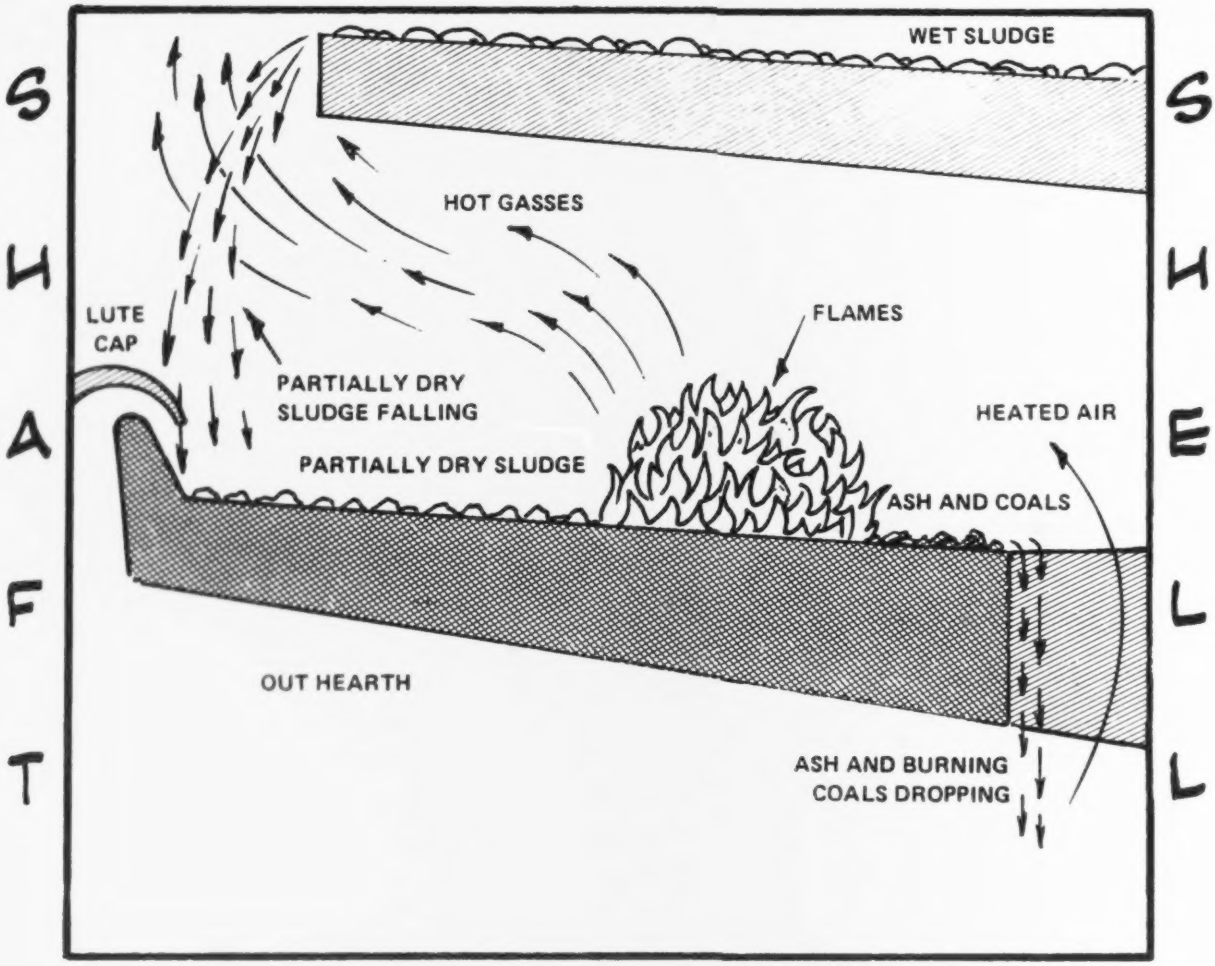

S
H
A
F
T
WET SLUDGE
HOT GASSES
LUTE CAP
FLAMES
PARTIALLY DRY SLUDGE FALLING
HEATED AIR
PARTIALLY DRY SLUDGE
ASH AND COALS
OUT HEARTH
ASH AND BURNING COALS DROPPING
S
H
E
L
L

Fig. 3.36 Flames in middle of an out hearth

2. The moisture content of the sludge feed to the furnace.

   The drier the cake being fed to the furnace, the less fuel will be required to dry the sludge to maintain a good burn. Ideally, the *MOISTURE* content of the furnace feed should not exceed 75 percent. Every bit of moisture entering the furnace requires a great deal of fuel to be consumed in the process of evaporation.

3. The volatile content of the solids in the sludge feed.

   The higher the percent volatile material, the less fuel will be required. Assuming, of course, a reasonable percent solids in the sludge.

4. Cake feed rate.

   A constant cake feed rate coupled with the above mentioned items helps to reduce the quantity of fuel required.

3.5332 Air Flow. The draft or vacuum in the furnace is the direct cause of all air flow within the MHF. The draft within the furnace is caused by the induced draft fan and by the convection flow caused by the temperature differentials between the interior of the furnace and the atmosphere. Convection flows also explain why there is a draft within the MHF when the induced draft fan is off and the by-pass damper is open.

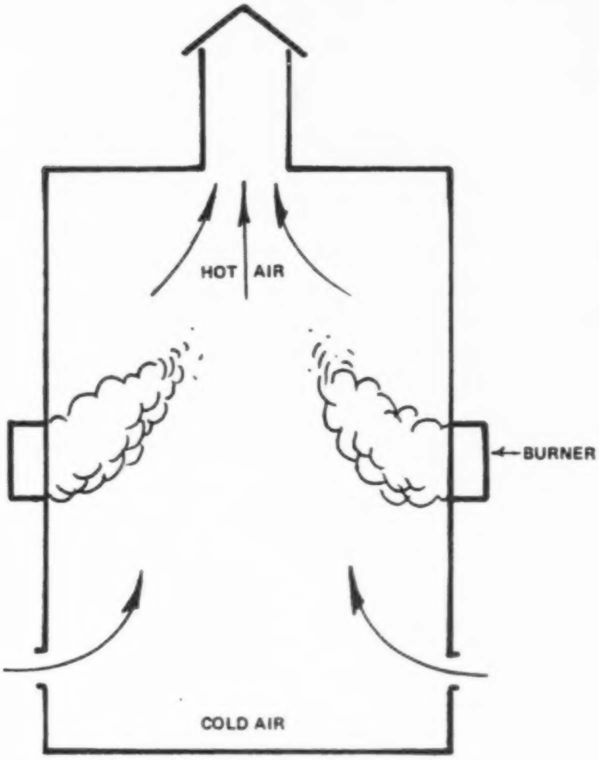


Fig. 3.37 Convection air flow in an MHF

Convection air flow develops in the MHF as a result of air being heated by the burners in the MHF (Figure 3.37). The air flow within an MHF is from the bottom to the top. The flow occurs because as the air in the MHF is heated and rises, it creates a vacuum in the bottom of the furnace. This vacuum causes cooler, outside air to flow into the bottom of the furnace where the air is heated and rises. The term used to describe this process is called "convection flow" and "draft" is the measurement of the negative pressure or vacuum created by this flow.

The draft in the furnace is measured either in tenths of inches or millimeters of water column. Relating this height of column to pounds per square inch or kilograms per square centimeter, you must remember that 1 foot (304.8 mm) of water column is equal to 0.434 psi (0.0305 kg/sq cm). Therefore, one inch (25.4 mm) of water column equals 0.0378 psi (0.00266 kg/sq cm) and one tenth of one inch (2.54 mm) water column equals .0038 psi (0.00027 kg/sq cm). A very small pressure.

We want only enough air in the furnace to allow for the complete combustion of the volatile matter in the sludge cake. Therefore, we must control the draft within the furnace carefully. The normal range of draft within the MHF is from 0.05 to 0.2 inches (1.3 to 5.1 mm) of water.

In the multiple-hearth furnace it is extremely important to remember that an excess amount of air must be available at all times. This excess air assures that all volatiles (combustibles) can contact sufficient oxygen to insure complete combustion. If there is inadequate oxygen present, there will be incomplete combustion, which means smoke. Smoke indicates unburned hydrocarbons. While remembering that the human eye cannot detect the ultra-violet spectrum of the flames, a visual inspection of the burning zone can give a good indication of the amount of excess air present.

1. A darker flame, ending in a curlicue of smoke, with a dull smokey atmosphere means there is a lack of air (volatile hydrocarbons are carbonizing).
2. A bright, sharp flame indicates excess air, but not how much. Decrease the amount of excess air which will decrease the amount of fuel being burned, *AS LONG* as the stack plume does not become smokey, black, light blue, or brownish.
3. Short blue flames on the lower hearths indicate burning of fixed carbon which means there is adequate excess air.

There are two ways of getting excess air into the furnace. These are:

1. By evenly opening the smaller doors and possibly the big doors a little on the *BOTTOM HEARTH,* or opening the dampers of the air ducts, the incoming air rushes over the hot ash and is preheated while the ash is being cooled.
2. Opening the center shaft cooling air return damper allows the hot air to be returned if the furnace is so equipped.

Since air is approximately 21 percent oxygen, an oxygen content of about 8 to 12 percent in the furnace gas indicates that adequate excess air has been added to insure complete combustion.

The oxygen analyzer is the operator's tool for determining the excess air in the furnace. Drawing samples from the exhaust after the induced draft (I.D.) fan and using the analyzer determines the amount of oxygen remaining after combustion. The oxygen analysis is sent to the panel for the operator's reaction. Fluctuation in the oxygen is an indication of change in the furnace. A rapidly decreasing excess oxygen usually means that the fire is growing and is removing the excess oxygen. This is a common occurrence during a burnout.

An increasingly excess oxygen reading can mean a reduction in fire. By adding air above the fire, a false indication of excess oxygen will be given. Since it is a false reading, a visual inspection of the burn for smoke should be made until the air above the fire can be removed.

General rules for excess oxygen change are summarized as follows:

O_2 Change	Cause
Increase O_2	- Decreasing fire and/or increasing air above fire zone.
Decrease O_2	- Increasing fire and temperatures.

The oxygen demand of the furnace changes with the amount of combustion going on inside the furnace. Too much cool air is a waste of fuel and too little air causes smoke. Control must be maintained to provide the proper amount of air to fit the demands of the furnace.

3.5333 Combustion. Combustion is a chemical reaction which requires oxygen, fuel, and heat. In the furnace, air provides oxygen, the primary fuel is sludge, and the heat comes from the burning sludge. Fuel is burned as an auxiliary fuel in the burners to help provide the heat needed to burn the sludge and to preheat the furnace to combustion temperatures.

3.5334 Air Flow and Evaporation. Above the fire the furnace has wet, cold sludge in it. As the hot, dry air and combustion gases pass over the upper hearths, the heat is transferred to the sludge. At the same time the moisture in the sludge is evaporated, the dry gases pick up the moisture and carry it out of the furnace.

Return shaft cooling air (Figure 3.38) is the usable byproduct of the center shaft cooling air. The main shaft is doublewalled and cast in sections. The sections have tubular inner duct called a "cold air tube." The annular (ring shaped) space between the inner tube and the outer shaft wall serves as a passageway for hot air and is referred to as the hot air compartment. The central shaft and rabble arms are cooled by air supplied at a fixed quantity and pressure from a blower which discharges air through a housing into the bottom of the shaft.

Two or more rabble arms are held in shaft sockets above each hearth where the cold air tube as well as the outer shaft wall provide support. Each rabble arm has a central tube which conducts the cold air from the cold air tube to the extreme end of the rabble arm (Figs. 3.30 and 3.32). From there, the air goes through the outer air space in the arm, back toward the shaft and through the openings into the hot air compartments. Unused heated cooling air may be returned to the atmosphere by other means depending on the design.

The hot air compartment may be vented to atmosphere or the hot shaft air may be returned to the furnace for combustion purposes. Shaft return air is sent below the normal burn zone but still above the final ash cooling hearth.

THE SHAFT AIR TEMPERATURE
SHOULD NOT EXCEED A MAXIMUM
TEMPERATURE OF 550°F (290°C)

When the preheated shaft cooling air is not required for furnace operation, it is vented to the induced draft stack. This hot air will prevent "stream" plume formation. As it exits the furnace at the top of the center shaft, the operator may direct the path of this heated air. By means of two mechanically linked dampers (called proportional dampers), the operator at the main control panel directs the heated air out into the atmosphere or back to the furnace as hot air return.

Hot air return should be used with some discretion. The hot air return can: (1) provide a fast source of air (oxygen) within the furnace; (2) use less fuel to heat the air; (3) reduce smoking; or (4) increase the drying rate of sludge. Returning too great a volume has the disadvantages of blowing "fly ash" as well as "dumping" the return air into the furnace at one point rather than distributing it evenly around the hearths. Remember that as the air passes over the hot coals, some of the oxygen is being removed before it gets to the fire.

3.5335 Recommended Furnace Operating Ranges. Table 3.25 summarizes the general temperature and pressure ranges maintained on the various hearths when burning wastewater sludge.

TABLE 3.25 MHF OPERATING RANGES

Location	Range	Optimum
Hearth #1 (Gas Exit)	700 to 1,000°F^{a}	As low as possible
Burning Hearth	1,300 to 1,700°F^{a}	1,600°F^{a}
Bottom Hearth	200 to 800°F^{a}	200°F^{a} or As low as possible
Scrubber Inlet	100 to 300°F^{a}	150°F^{a}
Furnace Draft	0.05 to 0.2 inches^{b} of water	0.1 inch^{b} of water
Furnace Oxygen	8 to 12 percent	10 percent

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[a] (°F − 32)5/9 = °C
[b] inches × 25.4 = millimeters

3.5336 Alarm Systems. Almost all MHFs are equipped with an alarm system because of the speed at which the system will react to changes. The alarm system informs the operator of abnormal conditions. The operator should react to an alarm as follows:

1. Understand what malfunction is causing the alarm before pressing the acknowledge button. Many times a group of alarms will go off at one time. Find the alarm that is downstream from the rest of the alarms (for example, the ash bin is downstream from the center shaft).
2. Press the reset button to see if the alarm conditions still exist.
3. Try to restart the equipment that caused the alarm at the location of the equipment rather than from an alarm panel. *DO NOT FORCE IT TO RUN!* If it starts, restart all equipment that was shut down by the alarm. Press reset button.
4. If it does not start, make a brief visual inspection of the malfunctioning equipment.
5. Make a decision as to whether or not you can safely correct the problem.
6. Return to the panel and furnace and check the conditions. If you can fix the problem, you still must control the furnace. If you cannot fix the problem, burn out the remaining sludge or maintain as stable a condition as possible. If you must burn out the remaining sludge, try to control the burnout temperature.

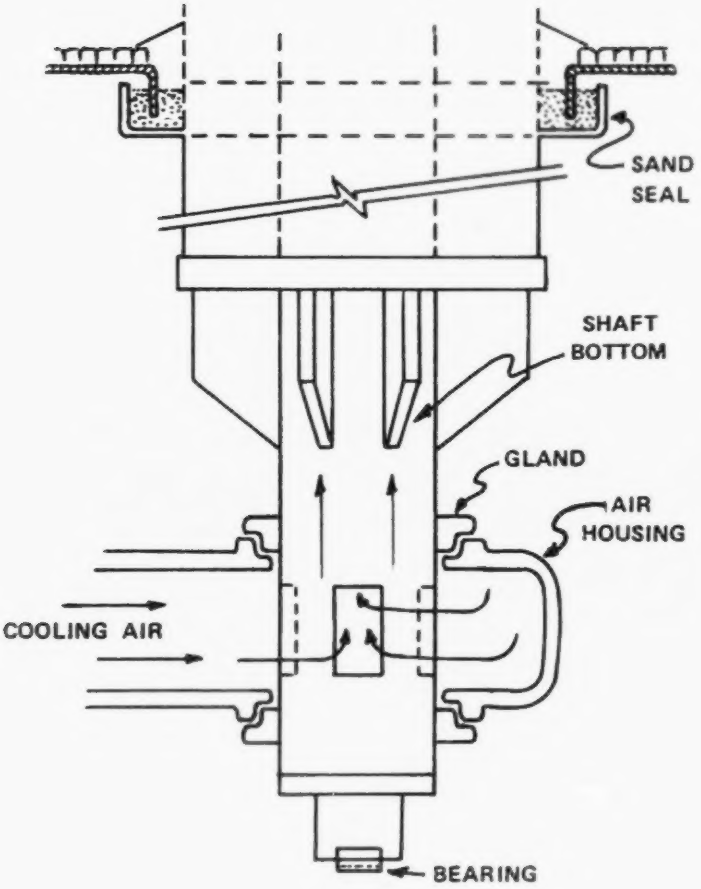

SAND SEAL
SHAFT BOTTOM
GLAND
AIR HOUSING
COOLING AIR
BEARING

Fig. 3.38 Shaft cooling air return system

3.5337 Burnouts. A burnout occurs when the sludge feed has been stopped and the fire continues to burn. Eventually, the final quantity of sludge is dry enough to burn and does. This final rapid burning of the last sludge can cause high temperatures in the furnace that can potentially cause damage to the furnace and its related equipment. Operators must control the burnout temperatures. The ideal burnout is to have only a 100 degree Fahrenheit (55 degree Celsius) increase in any hearth temperature during a burnout. This requires concentration by the operator on the furnace's changing conditions: fire position, sludge remaining in the furnace, shaft speed, temperatures, excess oxygen, burner settings, and the ability to be smarter than the furnace by anticipating the fire's next move long before it happens. This way the operator makes adjustments which limit the fire's final burnout.

The operator may choose to increase the shaft speed in preparation for the burnout. The purpose is to move the last sludge lower in the furnace before it burns. This results in keeping the high temperatures away from the top of the furnace. The operator must be careful not to allow unburned sludge to pass through the furnace. The high shaft speed will also generate a higher furnace temperature because of the increased rate at which fresh fuel is available to the fire.

There are three basic adjustments that control the fire during a burnout:

1. Opening doors at or just above the fire,
2. Stopping and restarting the shaft or changing the shaft speed, and
3. Reducing or shutting off burners.

1. Opening doors. By opening the doors, a large volume of cold air enters the furnace. This replaces the heat needed for combustion and cools the fire. The draft must be maintained (.07 to .2 inches or 1.8 to 5 mm water column) by opening the induced draft damper. To prevent an induced draft fan overload, air ports and doors below the fire and the hot air return can be closed to reduce the total air flow. The air flow removed from underneath can now be added directly at the fire for combustion and also above the fire where it will have a cooling effect.

   Cooling air will only provide short-term control. The fire will eventually generate more heat than can be compensated by cooling air. Another control must be used *QUICKLY*.

2. Stopping the center shaft. Stopping the center shaft will remove the fresh fuel for the fire which will cause the fire to die down. By starting and stopping the shaft, the operator controls the amount of fuel available for the fire to burn. The shaft should be stopped no longer than three minutes. When it is started again, a low shaft speed (0.4 to 0.7 rpm) will help control the fire by turning over the fresh sludge at a slower rate. When the temperature rises again, the shaft is stopped again. This procedure is continued until the fire does not cause a high temperature jump. Once the temperature starts to drop with the shaft running, close up the furnace doors to control the temperature change. Once the fire has burned out completely, the operator can switch from induced draft to natural draft to control the temperature.

DO NOT ASSUME THE CAKE HAS BURNED OUT BY LOOKING AT THE TEMPERATURES SHOWN IN THE TEMPERATURE RECORDER. OPEN THE DOOR ON EACH HEARTH AND LOOK IN CAREFULLY.

3. Reducing or shutting off the burners. During a burnout, the sludge needs little or no heat from the burners. Once the fire starts to increase the temperatures, reduce and then shut off the burners. This will provide two advantages:
   1. Temperatures will be reduced, and
   2. Gases from the burner will be removed. This missing gas volume can be replaced by cooling air above the fire.

Once the temperature starts to fall, the burners can be relit to control the dropping temperatures.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.53I List the three distinct zones in a furnace.

3.53J List the factors that influence the amount of fuel required.

3.53K What three factors are essential for combustion and what is the source of each factor?

3.53L Shaft speed adjustment may be required as a result of changes in what factors?

3.53M What is a burnout?

3.534 General Operational Procedures (Start-Up, Normal Operation, and Shutdown)

MHF operational procedures are based on consideration of the interrelationships between air flow, shaft speed, and temperature.

The first step in starting an MHF is to set the water flows to the scrubbers and then start the induction draft (I.D.) fan. Once the I.D. fan is at the operational speed, you then want to set your I.D. damper to maintain the desired draft (0.1 inch or 2.54 mm water column). At this point you begin the "purge cycle" (removing unwanted gases from the furnace). The purge cycle is usually controlled by a timer and will last from 3 to 10 minutes. At the end of the purge cycle (usually indicated by a panel light), you start the shaft cooling air fan, the combustion air fan, the ash system, and the center shaft. You are now ready to start heating up the MHF.

IMPORTANT

DUE TO THE NATURAL CHARACTERISTICS OF REFRACTORIES (HEARTHS), THE MHF MUST BE HEATED UP AT AN EXTREMELY SLOW RATE. THEREFORE, THE FOLLOWING DRY OUT MUST BE FOLLOWED EXACTLY.

The first step in the warm-up of an MHF is to light the pilot lights on the bottom hearth. The temperature is then brought up to 200°F (93°C). *DO NOT* allow the temperature to exceed 200°F (93°C) at any point in the furnace. Hold the temperature at 200°F (93°C) until the refractory is dry and warm. To check this, open the door of the MHF and observe the refractory where it meets the steel shell. The refractory and the shell *MUST* be dry. If it is dry, carefully feel the refractory where it joins the shell. The refractory at this point should be warm to the touch. The time required for the dry-out/warm-up varies depending on how long the furnace has been out of service. If the temperature of the hearth never dropped below 200°F (93°C), the dry-out/warm-up will not be required, but if the MHF has been off line for an extended period of time, the dry-out/warm-up may take from several days to a week. If there is any question as to whether the furnace is dry or warm, *LET THE FURNACE WARM-UP* for an additional period of time. Remember this is one of the most critical periods in MHF operation.

Once the refractory is warm, the operator may proceed to heat up the unit at a rate of 50°F/hr (28°C/hr). This rate of temperature increase must be maintained carefully, even at the expense of adding air for cooling.

Once the temperature on a given hearth reaches 1,000°F (540°C) *THAT HEARTH'S* temperature may be raised at a rate of 100°F/hr (56°C/hr). This procedure is followed until the burning zone of the furnace reaches 1,600°F (870°C) at which point the feed to the furnace may be started.

NOTE: The same rate of temperature losses apply when the furnace is taken out of service. Drop the temperature at a rate of 100°F/hr (56°C/hr) to 1,000°F (540°C) and then lower the temperature at 50°F/hr (28°C/hr) when the temperature is below 1,000°F (540°C).

When feed is introduced to the furnace, the temperatures will initially drop. This is due to the cooling effect of the wet cake. Once the cake reaches the burning zone, however, the cake should start to burn and the temperature profile will even out. Once this profile is established, the profile should be maintained within a 200°F (110°C) range. The burn is then maintained by use of the shaft speed, return air, and the burners.

The sludge cake has a very high heating value (approximately 10,000 BTU/lb volatile solids or 23,260 kilojoules/kg volatile solids). In many cases the volatile content of the sludge cake is high enough that the cake will burn without the additional heat input from the burners. This condition is called an autogenous (aw-TAW-jen-us) burn. To achieve this condition, the sludge cake must generally exceed 25 percent total solids and 70 percent total volatile solids. To maintain an autogenous burn condition, a constant steady-state sludge feed is mandatory. An autogenous burn represents the most economical mode of MHF operation.

Even when an autogenous burn cannot be established, fuel usage is affected by the heat released by the burning volatile material in the sludge cake. The MHF should be operated on a continuous basis when the unit is in operation to take advantage of the heat from the burning sludge. Remember that all the fuel used to maintain the temperatrue on a furnace at a standby mode represents money added to the total cost of solids disposal.

Another benefit of continuous operation is an increase in refractory life. As the MHF is cycled up and down in temperature, the refractory expands and contracts with the temperature changes. As this expansion and contraction occurs, the joints between the hearth bricks open and close. As these joints open, ash falls into the joint. When the MHF is later reheated, the surrounding brick expands and compresses the ash and a tremendous pressure is exerted on the brick. This process occurs repeatedly until the brick finally breaks.

Ultimately there is a trade-off between fuel cost to maintain furnace temperatures and the cost of refractory repair. As a general rule, MHF operation is most economical when scheduled on as nearly a continuous a basis as possible.

3.535 Common Operating Problems (Troubleshooting)

3.5350 Smoke. The most common cause of smoke or air emissions from an MHF is low oxygen content. This means there is insufficient oxygen in the furnace to completely burn the hydrocarbons. The solution to this problem is to add air to the furnace.

Air may be added to the furnace through the doors, air ducts, or through the use of the shaft cooling air return. Just as important as the excess air is where you add the air. Air generally should be added at or below the fire.

NEVER ADD AIR ABOVE THE FIRE, UNDER NORMAL CONDITIONS.

3.5351 Clinkering. Many times hard, rock-like clinkers will form within the furnace. If this situation is allowed to continue, the clinkers may grow to a point where the drop holes plug and the rabble teeth become blinded (plugged). The solution to clinkering lies in understanding how a clinker is formed.

A clinker is nothing more than melted ash that has cooled. The only temperatures in the furnace high enough to melt the ash are the actual flame temperatures of the burners and the flame from the burning sludge. However, the sludge flame temperature is rarely high enough. Therefore, as a general rule, the solution to clinkering lies in distributing the burner input into the MHF. An example of this would be running burners on separate hearths at lower firing rates.

If this does not correct the problem, it will be necessary to reduce the feed rate to the furnace and have the cake analyzed for mineral content and for excessive levels of polyelectrolyte.

3.5352 Inability to Stabilize Burn. If you cannot stabilize the burn, the first place to look for a problem is your feed cake. The MHF loading must be constant with little or no change in moisture or volatile content.

If the feed is constant, then the operator may be making other process changes too quickly. The ultimate effect of any process change to a furnace will show-up one hour after the change was made. Therefore, make one change at a time and *WAIT* for the results.

3.536 Safety

An MHF has several safety considerations above those in the rest of the treatment plant. These considerations all revolve around the fact that the MHF uses high temperatures to destroy the solids. Therefore, *TREAT EVERYTHING AS IF IT WERE HOT!*

Anytime you are in the furnace area, wear protective clothing including heavy leather gloves, face shield, hard hat, long sleeve shirt and long pants.

Never wear synthetic fabrics. The heat from the furnace can cause synthetic fabrics to ignite and act like napalm on your skin. Wear clothing made of cotton.

Never look directly into a furnace door when the furnace is in operation. Always approach the door from an angle and look in at an angle.

A furnace, when out of operation, is a confined space. Treat it accordingly, checking the atmosphere before entering for toxic gases (hydrogen sulfide), explosive conditions, and an oxygen deficient atmosphere.

Always check the temperature of the ash bed before entry. Though the furnace may be cold, the ash bed may still be several hundred degrees under the surface.

Always lock out the main fuel control valve and the control power prior to furnace entry.

Check and verify the operation of all safety controls and interlocks on a regular basis.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.53N At what rate of temperature increase do you bring a cold furnace up to temperature?

3.53O What is an autogenous burn?

3.53P Why is it desirable to operate an MHF on a continuous basis?

3.53Q What is the cause of smoke from an MHF and how can this problem be corrected?

3.53R What protective clothing should be worn when in the furnace area?

3.54 Facultative Sludge Storage Lagoons

Facultative sludge storage lagoons can serve three very important purposes:

1. Volume reduction. Volatile solids can be reduced by 45 percent and solids concentrations can be increased from two percent up to eight percent or more. Sludge concentrations as high as 25 percent solids have been obtained in the bottom layers of some lagoons.
2. Storage buffer. Storage is frequently required when sludge production is continuous and land disposal is affected by changing seasonal conditions.
3. Further stabilization. Anaerobically digested sludge is further stabilized in the storage lagoon by continued anaerobic biological activity.

Facultative sludge storage lagoons vary in depth from 10 to 16 feet (3 to 5 m). Surface areas are based on solids loadings of 20 to 50 pounds of volatile sludge solids per day per 1000 square feet of surface area (0.1 to 0.25 kg VSS per day per square meter). Surface aerators are commonly used to maintain aerobic conditions near the surface in order to avoid odor problems.

There should be enough lagoons to allow each lagoon to be out of service for approximately six months. Stabilized and thickened sludge can be removed from the basins using a mud pump mounted on a floating platform.

QUESTION

Write your answers in a notebook and then compare your answers with those on page 260.

3.54A List three purposes of facultative sludge storage lagoons.

3.6 LAND DISPOSAL OF WASTEWATER SOLIDS (by William Anderson)

3.60 Need for Land Disposal

The alternatives for land disposal and/or utilization of wastewater solids are shown in Figures 3.39, 3.40, and 3.41. The alternatives for sludge are placed in either of two categories based on the process used after stabilization (digestion or chemical stabilization); (1) dewatering to about 20 to 30 percent solids, or (2) concentration during liquid storage to 6 percent solids.

Disposal and/or utilization of sludge following stabilization without additional treatment to reduce water content is to be avoided for the following reasons:

1. Water content (97 to 98 percent) of stabilized sludge is too high to permit landfill or composting operations.
2. Sludge application and surface runoff problems in the wet season are difficult to handle.
3. Land requirements necessary to evaporate the excessive moisture are unreasonable.

3.61 Regulatory Constraints

Wherever various methods of sludge disposal are evaluated, consideration must be given to the requirements of various regulatory and planning authorities of the local, state, and federal agenices. Unfortunately, many of the requirements are still in a formative stage. Important restraints include allowable emissions to the atmosphere from furnaces, groundwater and surface water limitations, and the health aspects of sludge applied to land involved in the food chain.

3.610 Regulation of Sludge Disposal

Sludge may be disposed of in a sanitary landfill at the treatment plant site. Under these conditions, surface runoff must be prevented. Also, percolation of leachate to groundwater must be carefully controlled or eliminated.

At dedicated land disposal (DLD) sites, stabilized sludge is applied to the land and then ploughed under. At sites of this type, sludge must be covered the same day it is applied. Public access must be avoided because pathogens or parasites may not have been removed.

3.611 Regulation of Sludge Reuse in Agriculture

If sludge is to be reused for agricultural purposes, the treatment plant owners should also own nearby land to assure necessary monitoring and controls. Use of sludge on agricultural land requires close monitoring of cadmium levels and any other heavy metals, as well as toxic substances and pathogens applied to the land. Because of the potential problems from toxic substances, viruses and pathogens, the application of sludges on food crops should only be attempted at this time when careful monitoring is involved.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.61A1 What are two important restraints regarding the disposal of sludge?

3.61B Why should sludges not be applied to food crops?

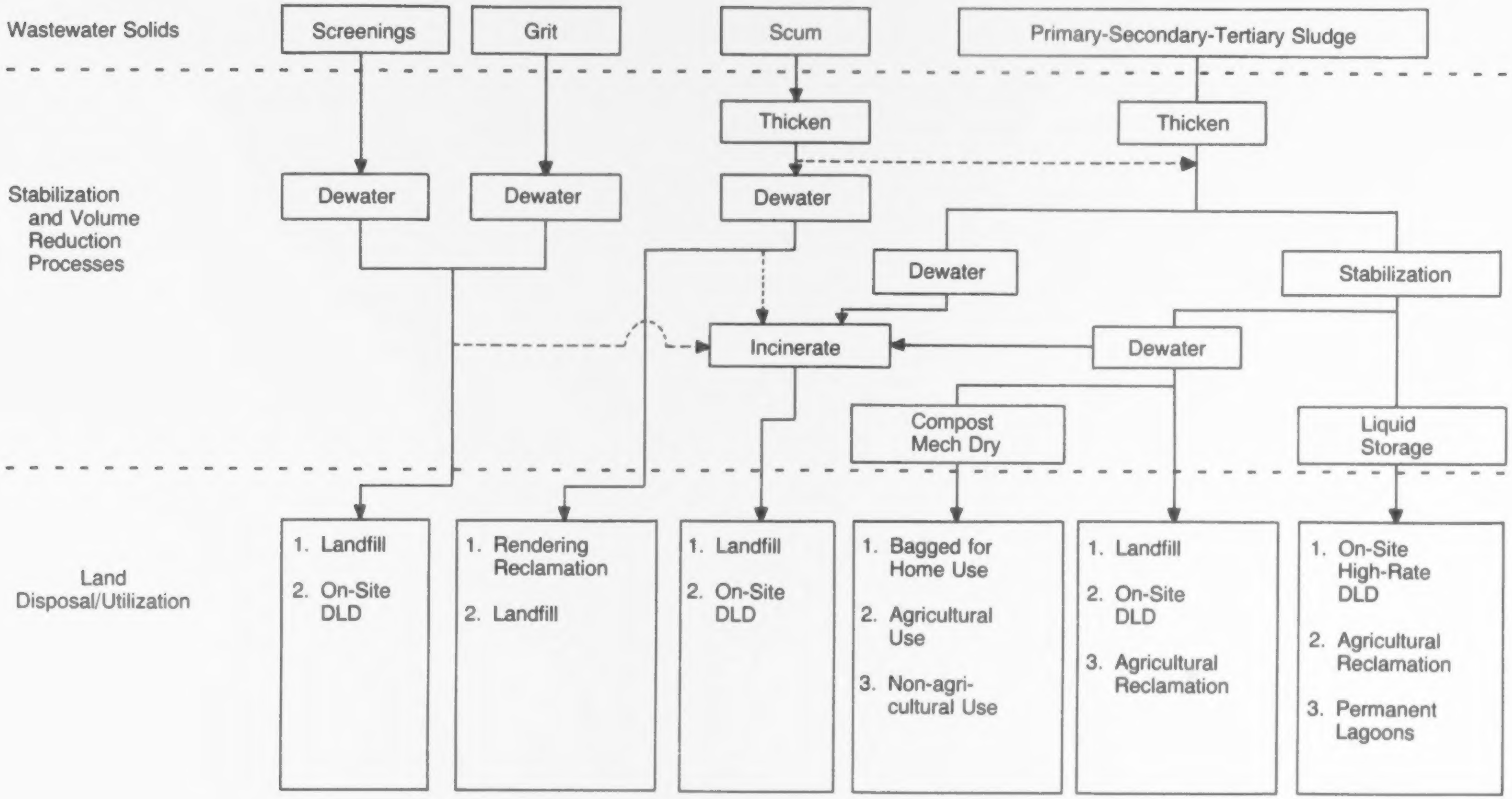
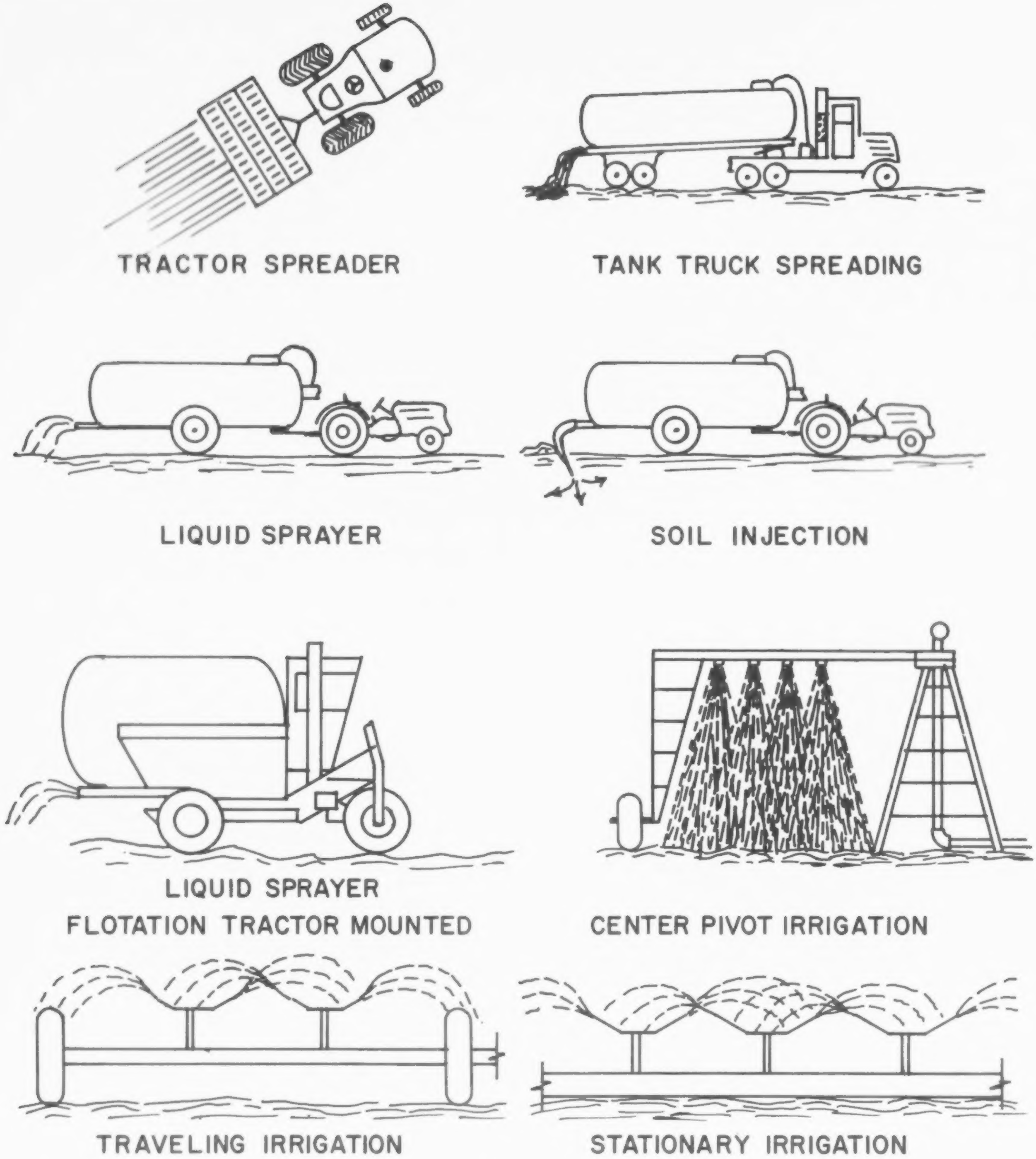

Wastewater Solids
Screenings
Grit
Scum
Primary-Secondary-Tertiary Sludge
Thicken
Thicken
Stabilization and Volume Reduction Processes
Dewater
Dewater
Dewater
Dewater
Stabilization
Incinerate
Dewater
Compost Mech Dry
Liquid Storage
Land Disposal/Utilization
1. Landfill
2. On-Site DLD
1. Rendering Reclamation
2. Landfill
1. Landfill
2. On-Site DLD
1. Bagged for Home Use
2. Agricultural Use
3. Non-agricultural Use
1. Landfill
2. On-Site DLD
3. Agricultural Reclamation
1. On-Site High-Rate DLD
2. Agricultural Reclamation
3. Permanent Lagoons

Fig. 3.39 Alternatives for land disposal and/or utilization



TRACTOR SPREADER

TANK TRUCK SPREADING

LIQUID SPRAYER

SOIL INJECTION

LIQUID SPRAYER
FLOTATION TRACTOR MOUNTED

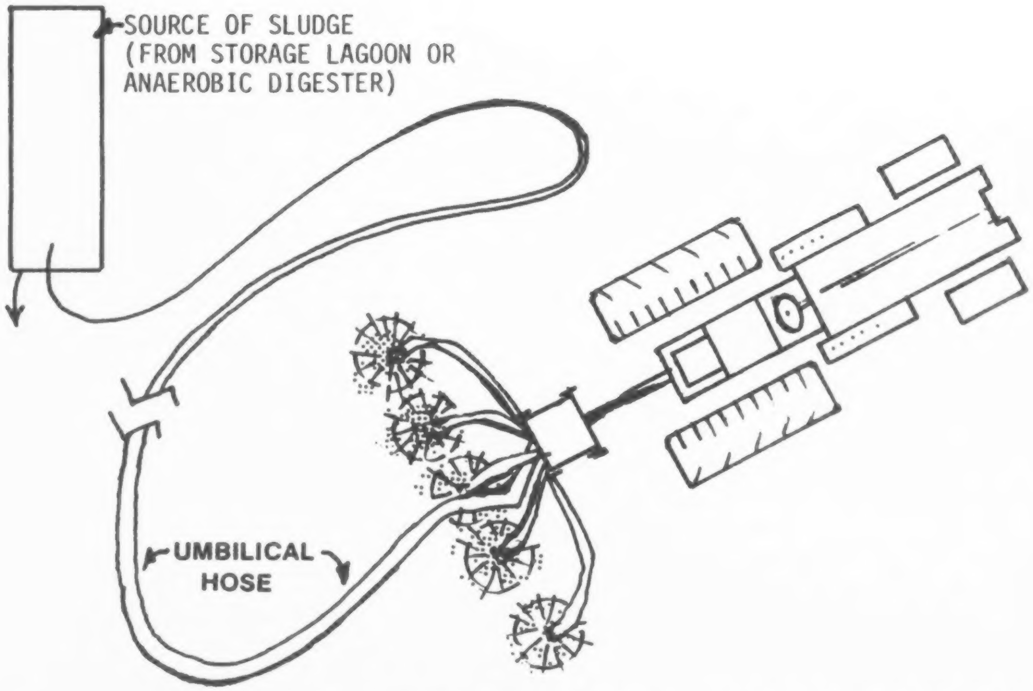
CENTER PIVOT IRRIGATION

TRAVELING IRRIGATION

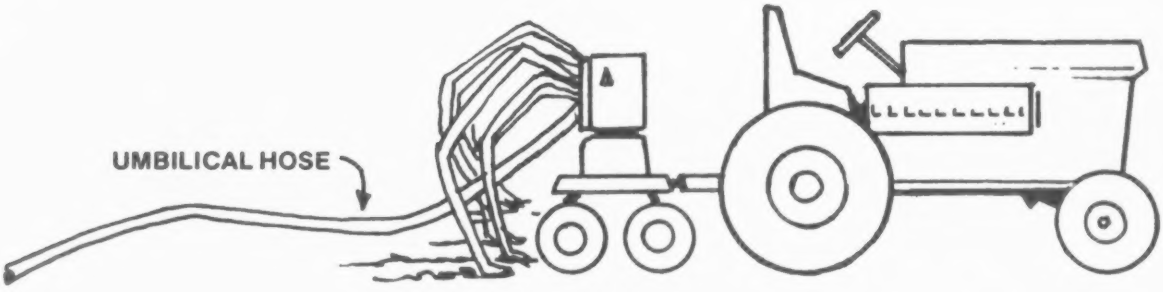
STATIONARY IRRIGATION

1. Adapted from "Sludge Processing and Disposal – LA/OMA Project"

Fig. 3.40 Typical liquid sludge application systems on land

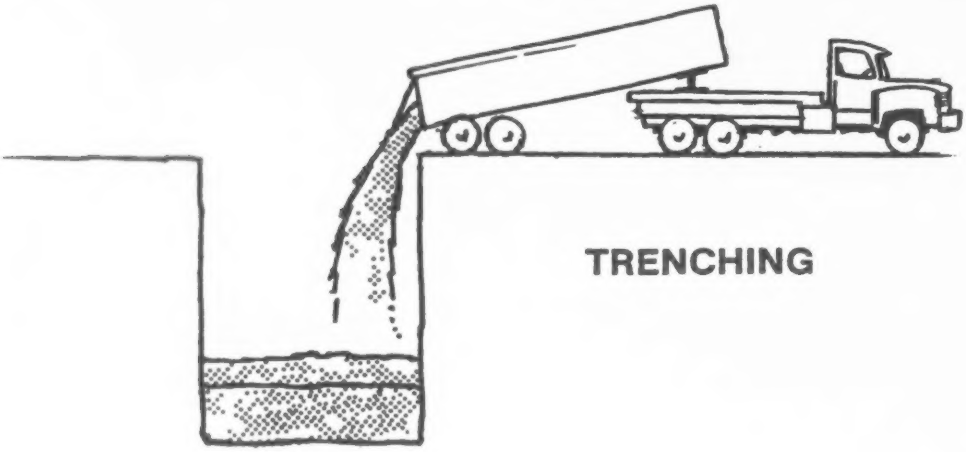

SOURCE OF SLUDGE
(FROM STORAGE LAGOON OR
ANAEROBIC DIGESTER)
UMBILICAL
HOSE

UMBILICAL CORD TRACTOR — SURFACE SPREADING

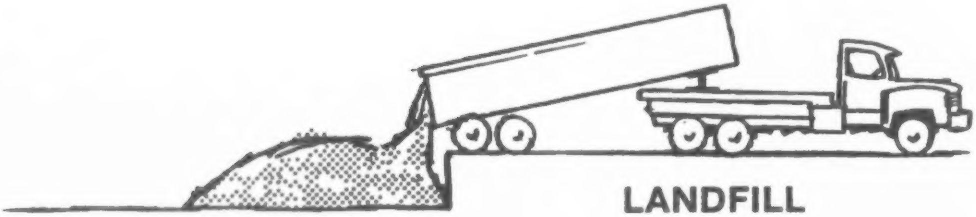

UMBILICAL HOSE

UMBILICAL CORD TRACTOR — SOIL INJECTION

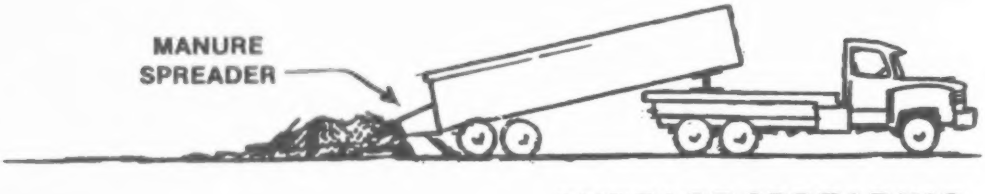
Fig. 3.40 Typical liquid sludge application systems on land (continued)



TRENCHING



LANDFILL


MANURE SPREADER

SURFACE SPREADING

Fig. 3.41 Typical dewatered sludge application systems on land

3.62 Disposal Options

3.620 Stabilized Sludge — Dewatered

STORAGE. Storage often must be provided in the sludge treatment system to accommodate differences between disposal rates and production rates. Sludge storage is effective when part of a liquid treatment system, such as anaerobic or aerobic digesters. Mechanically dewatered sludge is very difficult to store for any length of time. If lime and/or ferric chloride have been used to condition sludge for mechanical dewatering, the sludge may be stored for a longer period than if polymers were used. Three to five days are usually the limit for successful storage of mechanically dewatered sludge. Dewatered sludge from drying beds or drying sludge lagoons often can be stored for long periods of time in open stockpiles.

TRANSPORTATION. The number of trucks required to haul the dewatered stabilized sludge cake to the disposal site must be determined. Route possibilities should have been evaluated in the Environmental Impact Report for the project. Round-trip travel, loading, and unloading time need to be estimated (about 2-½ hours per 50 mile round-trip). Operating hours for truck transport also must be considered. If the transportation hours of operation are less than the hours of operation of the dewatering facility, storage will have to be provided at the dewatering facility. Usually it is not desirable to deposit sludge cake at a landfill on Saturdays, Sundays, or holidays. However, if the dedicated land disposal (DLD) site is located at the treatment plant site, sludge cake may be deposited at any time. On-site dedicated land disposal sometimes uses pneumatic ejection pipelines for transporting material to the disposal site. Agricultural reuse is often seasonal and trucking must always be at the pleasure of the farmer, not the operator of the treatment plant.

3.6200 Sanitary Landfill Disposal. Sludge cake (20 to 30 percent solids—discharged from the dewatering machines (centrifuges, vacuum filters, or filter presses) or (50 to 60 percent solids) removed from drying beds or drying lagoons (see Chapter 12, Section 12.7, "Digested Sludge Handling") can be transported to a sanitary landfill for disposal with the municipal refuse. The impact on the capacity of the landfill needs is determined as shown by the following calculation:

Given: Rate of Municipal Refuse Deposit, D tons/day
Rate of Sludge Cake Production, P cu yd/day

Assume: A Compacted Density of 560 lbs/cu yd

Find: The percent of increased usage of landfill, U.

$$\text{Usage, \%} = \frac{560 \text{ lbs/cu yd} \times \text{P, Sludge Cake, in yd/day} \times 100\%}{2000 \text{ lbs/ton} \times \text{D, Refuse Deposit, tons/day}}$$

The additional water associated with the stabilized sludge will provide better compaction in the landfill which will slightly reduce the percentage of increased usage. The landfill operator must be able to and willing to accept the sludge cake. A higher rate may be charged for sludge cake if special handling is needed.

LANDFILL MOISTURE ABSORPTION CAPACITY. The water balance of a landfill is important in minimizing leachate formation. The absorption capacity of the landfill should be investigated when adding materials with large amounts of water such as sludges. *A GENERAL GUIDELINE IS THAT NO MORE THAN 25 TO 40 GALLONS OF WATER PER CUBIC YARD (125 TO 200 LITERS/CU M) OF REFUSE BE ALLOWED.*

PLACEMENT OF SLUDGE IN A LANDFILL. Direct dumping or tailgating of sludge cake on the working face of the landfill is the method used most often. However, the following factors need to be considered for large-scale operations:

1. Operators must work in the immediate area.
2. Compaction must be achieved.
3. The general public discharging trash at the landfill must be protected.

DURING DRY WEATHER, either open-air drying or mixing with soil cover material prior to placement in the landfill would improve the operation.

DURING WET WEATHER, direct disposal in trenches or pits would probably be necessary to avoid surface runoff contamination and extremely unpleasant working conditions.

3.6201 On-Site Dedicated Land Disposal (DLD). Sludge cake (20 to 30 percent solids) discharged from the dewatering machines (centrifuges, vacuum filters, or filter presses) and cake (50 to 60 percent solids) from drying beds and drying lagoons can be moved to an area (DLD) on the treatment plant site that has been dedicated to the disposal of sludge cake, incinerator ash, and dewatered grit and screenings. To avoid the potential problems of having future development immediately adjacent to the sludge disposal areas, buffer land adjacent to these areas should be acquired by the treatment plant.

Surface runoff control facilities must be provided.

1. Flood Protection. The disposal site should be protected from flooding by a continuous dike.
2. Existing Drainage. The existing drainage into the disposal site should be intercepted and directed outside the flood-protection dike.
3. Contaminated Runoff. Runoff from the disposal site should be collected in a detention basin and allowed to evaporate during the summer or recycled to the treatment plant headworks.

PLACEMENT OF SLUDGE CAKE IN A DEDICATED LAND DISPOSAL SITE. Several methods of placement of sludge cake in a DLD site can be used and are described in the following paragraphs.

TRENCHING. This method has been used in some areas for many years.

1. Shallow trenches. Construct a trench about 4 feet (1.2 m) deep. Add sludge to a depth of about 2 feet (0.6 m). Backfill the trench to its original grade. Substantial amounts of land are required. Small treatment plants can use pits instead of trenches.
2. Deep trenches. Construct a trench about 20 feet (6 m) deep. Add sludge cake in 2-foot (0.6 m) lifts with a 1 foot (0.3 m) soil cover over each lift. When the trench is full, place a 5-foot (1.5 m) soil cover on top and sow grass on this cover. An average annual cake production of 50 tons/day (dry) will require about 20 acres/year for disposal.

Trenching of sludge cake prevents rapid decomposition of organic material and rapid removal of water, both of which would reduce the sludge disposal volume. Also, the DLD site is unsuitable for many purposes when trenching operations are complete because the surface may not support much weight. Depending on the area available, a DLD site may not be suitable for retrenching at the end of 20 years. Additional land would then be required. Also, at the end of 20 years the ground surface elevation may have been raised about 5 to 7 feet (1.5 to 2.1 m).

Long-term effects of trenching on groundwater are unknown and depend on soil conditions and level of groundwater table. Water addition to the trench areas will be about 100 gal/cu yd (500 liters/cu m). This is 2½ times the 40 gal/cu yd (200 liters/cu m) criteria for sanitary landfills. Specific site evaluation is required to satisfy the regulatory agencies and trench liners or leachate control facilities may be necessary.

Trenching operations are most difficult and sometimes impossible during extreme wet periods. No matter how the sludge cake is moved to the DLD site, by truck or by pneumatic ejection pipelines, it must be mixed with soil and/or buried daily to avoid odor production. Bulldozers, roadgraders, or bucket loaders have been successfully used to mix the materials before placement. To operate in wet weather, either paved areas or a well prepared gravel base is needed. Also, rainwater that collects in the trenches or other working areas will have to be transported to a detention basin and allowed to evaporate during the summer or be recycled to the treatment plant headworks.

LANDFILLING. Landfilling of sludge cake is an aboveground operation of mixing or interlaying sludge with soil. Usually several feet is excavated beneath the existing ground surface to obtain sufficient soil for final cover material. The excavated site is used as a cell where the sludge is mixed with the soil on a 1:1 ratio to aid in the placement of the material.

The problems and disadvantages of landfilling are similar to those listed for trenching.

a. Continued use of land 20 ac/yr (8 hectares/yr) for a 50 ton/day (45,000 kg/day) cake production.
b. Large quantities of water are added to the DLD site creating potential leaching.
c. Large excavation operations could damage existing natural (clay soils) groundwater protection.
d. Operations will raise the ground surface several feet.
e. Wet weather may prevent operations.

The advantages of landfilling sludge cake only are also similar to those for trenching.

a. Odor problems are minimized if sludge is covered each day.
b. Operations eliminate off-site transport.
c. Operations are fully controlled by the treatment plant.
d. Operations will also provide for on-site disposal of incinerator ash, dewatered grit, and screenings.

INCORPORATION INTO SURFACE SOILS. Mixing sludge cake with surface soils is a method that minimizes the problems of trenching and landfilling while retaining the advantages of on-site disposal. However, it is only recommended for use in dry weather because of the inability to move equipment and the odor-generation potential in wet weather. Extensive storage facilities are required to successfully practice this method of sludge cake disposal.

About 200 dry tons/acre (450,000 dry kg/hectare) could be applied in a 6-month dry season. Sludge could be reincorporated every few weeks after the soil/sludge mixture has dried. The DLD site may have a life of at least 40 years.

Equipment required for this operation consists of dump trucks or manure-type spreading equipment to haul dewatered sludge from the dewatering facility to the DLD. Since travel time should be minimal to an on-site DLD, only relatively small trucks are needed. Tractor, plow, and disking equipment also are necessary.

3.6202 Agricultural Reclamation. The main reasons for using wastewater solids for agriculture are to supply the nutritional requirements of crops and improve the tilth of the soil by adding humus without adversely affecting the crop produced, the soil, or the groundwater. Determining safe loadings within the above limitations requires a complete chemical and biological analysis of the wastewater solids coupled with an evaluation of soil types, crops, and irrigation practices.

APPLICATION RATE. The controlling factor for the sludge application rate may be the nitrogen requirement of the crop. Proposed long-term annual cadmium application criteria (0.5 kg/ha/yr proposed by EPA in 40 CFR 257.3-5) would allow an annual application of about 12.5 tons/acre (dry) (28,000 kg/ha) if the cadmium concentration was 18 mg Cd/kg dry solids. The following assumptions concerning nitrogen requirements and losses result in a 3.3 ton/acre/yr (dry) (7,400 kg/ha) sludge application rate.

1. Nitrogen content of 6 percent (dry weight basis of dewatered sludge).
2. One application per season before or between plantings (this procedure will require sludge storage facilities).
3. Rate of nitrogen mineralization is assumed to be an annual percentage of the remaining unmineralized portion. This results in 67 percent of the nitrogen being mineralized in 20 years. Nitrogen must be mineralized by the crop.
4. Loss of 25 percent of mineralized nitrogen to the atmosphere via volatization (ammonia release) and denitrification (nitrogen gas release). This loss is appropriate when sludge is disked into soil after application.
5. Crop demand is 200 pounds nitrogen/acre/yr (255 kg N/ha/yr) which is appropriate for many crops, including field corn.

$$\begin{array}{l}\text{Average Annual Sludge Application Rate, dry tons/acre} = \dfrac{\text{Annual Crop Nitrogen Demand, lbs/acre}}{\text{N Content, \% x N Mineral, \% x N Remain, \% x 2000 lbs/ton}}\\[1em] = \dfrac{\text{200 lbs/acre}}{\text{6\%/100\% x 67\%/100\% x 75\%/100\% x 2000 lbs/ton}}\\[1em] = \dfrac{\text{200 lbs/acre}}{\text{0.06 x 0.67 x 0.75 x 2000 lbs/ton}}\\[1em] = \text{3.3 dry tons sludge/acre}\end{array}$$

This analysis results in a low application rate that optimizes the reuse of the sludge nitrogen. If maximum nitrogen reuse was not an objective, higher sludge application rates (7.5 tons/acre or 16,800 kg/ha) could be made without injuring most crops. Nitrogen not used by the crop is denitrified during the winter when the soil becomes saturated with water. In this manner, nitrogen does not move downward in the soil to pollute groundwater.

Double-cropping in some areas may permit additional sludge application.

A zinc-to-cadmium (Zn/Cd) ratio lower than the EPA's guideline of 1000:1 may not have an adverse effect on crops, but monitoring of cadmium additions should be done on a regular basis.

METHOD OF APPLICATION. For low rates of sludge application (3.3 tons/acre/yr or 7,400 kg/ha/yr), good control over spreading methods is necessary. Manure spreaders or similar equipment are recommended for applying the sludge cake. A plowing and/or disking operation should follow closely to incorporate the sludge into the soil and cover it. Application of sludge to land controlled by the treatment plant affords maximum matching of disposal rates to plant production rates. Treatment plant agreements with individual land owners to spread sludge at certain times is less desirable because it reduces flexibility and reliability of operation. Monitoring of spreading sites will also be more difficult.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.62A What methods are available for the disposal of mechanically dewatered digested sludge?

3.62B What kinds of surface runoff control facilities must be provided at an on-site dedicated land disposal operation?

3.621 Stabilized Sludge — Liquid Process

Stabilized sludge can be disposed of in a liquid form (less than 10 percent solids) by: (1) high-rate incorporation into the surface soils of a site dedicated to land disposal (DLD); (2) low-rate application to agricultural sites; or (3) confinement in permanent lagoons.

STORAGE. Long-term storage (about 5 years) of sludge in facultative ponds immediately after digestion is recommended in order to:

1. Separate the daily production of sludge by the wastewater treatment process from the final disposal operation which may be seasonal, sporadic, highly variable in quantity, or subject to changing regulatory requirements;
2. Achieve substantial additional destruction of remaining volatile solids;
3. Maximize reduction of total volume by evaporation; and
4. Consolidate sludge to about 6 to 12 percent solids.

TRANSPORTATION. Liquid transportation of stabilized sludge is usually best accomplished by pipelines. This is especially true when high-rate on-site dedicated land disposal is used. Sludge concentrations much above four to six percent can be difficult to pump if the pipeline designer did not realize that the friction head loss increases when the sludge concentration increases.

For agricultural reuse of liquid stabilized sludges, trucks are usually the best means of transportation. The main advantage here is the flexibility of application sites. Sludge is dredged at 8 or 10 percent solids concentration and placed in large, specially designed tanker trucks on the order of 10,000 gallons (38 cu m) each or another type of truck. The material is flooded onto the field and disked in. If 10 percent solids concentrations are achieved, smaller open trucks with manure-type spreading devices fitted onto them may be used. This allows a less sophisticated operation and makes it easier for farmers to use existing equipment.

3.6210 High-Rate Dedicated Land Disposal. This process uses facultative sludge lagoons (FSLS) for storage and further stabilization prior to disposal.

Sludge is dredged from the facultative sludge lagoons and transported by pipeline to a dedicated land disposal (DLD) site which should be located adjacent to the facultative sludge lagoons. The DLD site should be loaded at a rate of about 100 dry tons/acre/yr (224,000 kg/ha/yr) and should be expected to operate for at least 40 years. Several sludge-spreading techniques have been tested for DLD operations, but shallow injection beneath the surface of the soil appears to be the most cost-effective and environmentally acceptable operation at this time.

RATE OF APPLICATION. The disposal system should operate over the months with the greatest potential net evaporation. Experiments indicate that an application of 100 dry tons/acre (224,000 kg/ha) of sludge at six percent solids concentration would be feasible over a four to six-month period in some areas.

The application rate results in a water loading rate of 1,570 tons/acre (3,520,000 kg/ha) for an average of 14 inches (36 cm) of water which must be evaporated. Despite the fact that evaporation from wet soil will be less than lake evaporation, there is no problem in meeting these evaporation needs in most arid areas.

DISPOSAL TECHNIQUES. Techniques for spreading sludge at six percent solids concentration dredged from the bottom of the facultative sludge lagoons include:

1. *RIDGE AND FURROW.* This technique could be very cost-effective if sludge could be made to flow down furrows, then after being applied, be covered by splitting the ridges and throwing the dirt over the top of the sludge in the furrows. The system seems to be unmanageable due to:
    a. Difficulty in maintaining the required relationship between the sludge viscosity (percent solids) and slope of the furrows.
    b. Clogging of sludge debris in the individual furrow gates of the distribution pipe.
    c. Cloddy, puddled soil that does not cover the sludge adequately. This may be due to soil characteristics. (However, this type of soil is usually needed for protection of the groundwater.)
2. *FLOODING.* This method consists of spreading the sludge as evenly as possible over the surface of the disposal area and then incorporating it with the soil. Flooding needs to be controlled with low (6 to 8 inch or 15 to 20 cm) borders or dikes running the length of the field in the direction of flow. The borders control the lateral movement of sludge, thus giving more uniform coverage. After spreading to an average depth of 1½ to 2 inches (3.8 to 5.1 cm), the sludge is turned into the soil with a large disk. At this application rate, the result is a well aerated soil/sludge mixture. At heavier applications, which may occur in some areas due to uneven flooding, the mixture approaches saturation and results in anaerobic conditions and some odors.

    A comparison of flooding with other methods produces the following disadvantages:

    a. Occasional odor problems from areas receiving excessive sludge application.

b. Difficulty of maintaining proper relationship between slope of the land and sludge viscosity makes even or uniform sludge application practically impossible.

However, the advantages of flooding over subsurface injection are:

a. Lower labor requirement and total cost. Cost comparison of the two systems in early 1978 showed that flooding would cost about $20/ton (2.2¢/kg), while subsurface injection would cost about $25.50/ton (2.8¢/kg).

b. Lower energy requirements since sludge would not be pumped through a small diameter hose and an injection system (both have high head losses).

3. *SUBSURFACE INJECTION.* Subsurface injection is presently the preferred disposal technique because of its ability to ensure consistent sludge application rates and to avoid odorous conditions. This system uses an umbilical cord (4 inch hose) tractor-mounted subsurface injector (Fig. 3.42) to distribute sludge at about 6 to 8 inches (14 to 20 cm) beneath the surface of the soil. The sweep on the injector unit opens a small cavity in the soil into which the sludge flows. After the sweep passes, the soil falls back into place leaving the sludge completely covered.

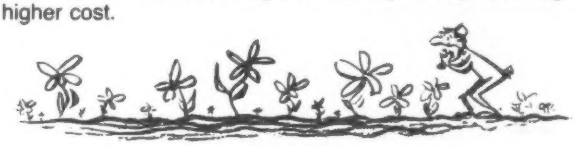
Sludge is transported from the dredge, operating in the facultative sludge lagoons, through pipes to the DLD site. Booster pumps may be needed at appropriate locations to move sludge the required distance. A pipeline extends into the DLD site, underground, and risers are appropriately located for hookup with the injection system. A 4-inch (10 cm) diameter flexible hose is attached to the riser and the tractor-mounted injection unit. Sludge application is directly beneath the surface of the ground and there is no visible evidence of the sludge after the injection unit moves on.

Problems may include:

a. Insufficient durability of the flexible supply hose.

b. Coordination of dredging and injection. When the tractor-injector is being turned at the end of a row, the flow must be stopped or relieved through a booster pump bypass system. This requires good communication between the injector, booster pump and the dredge operators.

The cleanliness and odor-free operation of subsurface injection make it a desirable disposal technique despite its slightly higher cost.



SITE LAYOUTS

1. Each dedicated land disposal site layout should have a gross area which includes area for drainage, road access, and injector turning.
2. Each site should be approximately 1,300 feet (400 m) wide. This dimension is determined by the 660-foot (220 m) length of the subsurface injector feed hose and the turn-around space required at each side of the field.
3. Each site should be approximately 800 feet (240 m) in length. This dimension is determined by the area required to allow one injector to operate continuously (six hours/day, five days/week during peak dry months. Consideration also must be given to the net evaporation during the dry month. Peak dry-month operation assumes one pass is made over the DLD site each week. During other harvesting months, it is assumed maximum operation will be limited to one injector making one pass every four weeks.
4. Each DLD site should be graded so that runoff drains (flows) from the center of the DLD to ditches on both sides. Runoff from these ditches should collect in a runoff detention basin at the end of the field. To prevent erosion, the maximum field slope should be held to 0.5 percent and the drainage ditches on the sides of each dedicated land disposal site should be designed so that the runoff water velocity does not exceed five feet per second. These field ditches should be "V" ditches with minimum side slopes of 4:1. These flat side slopes will permit vehicle access across the ditches during the dry weather for each dedicated land disposal site control. The collected runoff must be returned to some point in the liquid treatment process.
5. Each dedicated land disposal site should be surrounded by an isolation berm designed to keep uncontaminated surface runoff out and contaminated DLD site runoff in. The berm should be 15 feet (4.5 m) wide at the top and should be provided with 3:1 side slopes. The top of the berm should be finished with an all-weather gravel road.
6. Each dedicated land disposal site should be provided with an all-weather gravel access road to assure light truck access at all times to its isolation berm system.
7. Capability to purge sludge from the dedicated land disposal piping without discharging excessive purge water on the dedicated land disposal site must be provided.

SYSTEM OPERATIONAL CRITERIA

1. Dedicated land disposal sites should be loaded at a minimum of 100 tons (dry weight) per acre (224,000 kg/ha) of harvested sludge per year.
2. Dedicated land disposal sites should be disked as required to assure all sludge is covered daily. Intermittent disking is helpful in drying the fields quickly.
3. Harvested sludge piping should be flushed and purged at the end of each day's run. Sludge purged from piping should be injected into the disposal site. When starting each day's operation, liquid within harvested sludge piping should be purged, as much as possible, back to the facultative sludge lagoons.

EQUIPMENT NEEDS. The operation of the dredge is very important to the efficient application of sludge to the DLD site. This operation should be able to average 6 percent solids concentration, although even with a 4½ percent average solids content, the operation would still be quite effective. The greater the solids content, the more efficient the operation becomes since the system is limited by the amount of water which must be evaporated. Problems may be encountered trying to maintain a constant solids content in the dredged material since the sludge mass in the facultative sludge lagoons shifts from time to time.

3.6211 Agricultural Reclamation. This process uses facultative sludge lagoons, as described previously for sludge storage, and further stabilization prior to its use on nearby cropland. The purpose of this process is to maximize reuse of the nutrient components of the sludge. Some degree of control must be exercised over the land to be used for sludge spreading in order to ensure that full sludge utilization is guaranteed each year. Short of such a guarantee, a backup disposal system may be necessary.

TRACTOR AND INJECTION UNIT

INJECTION UNIT

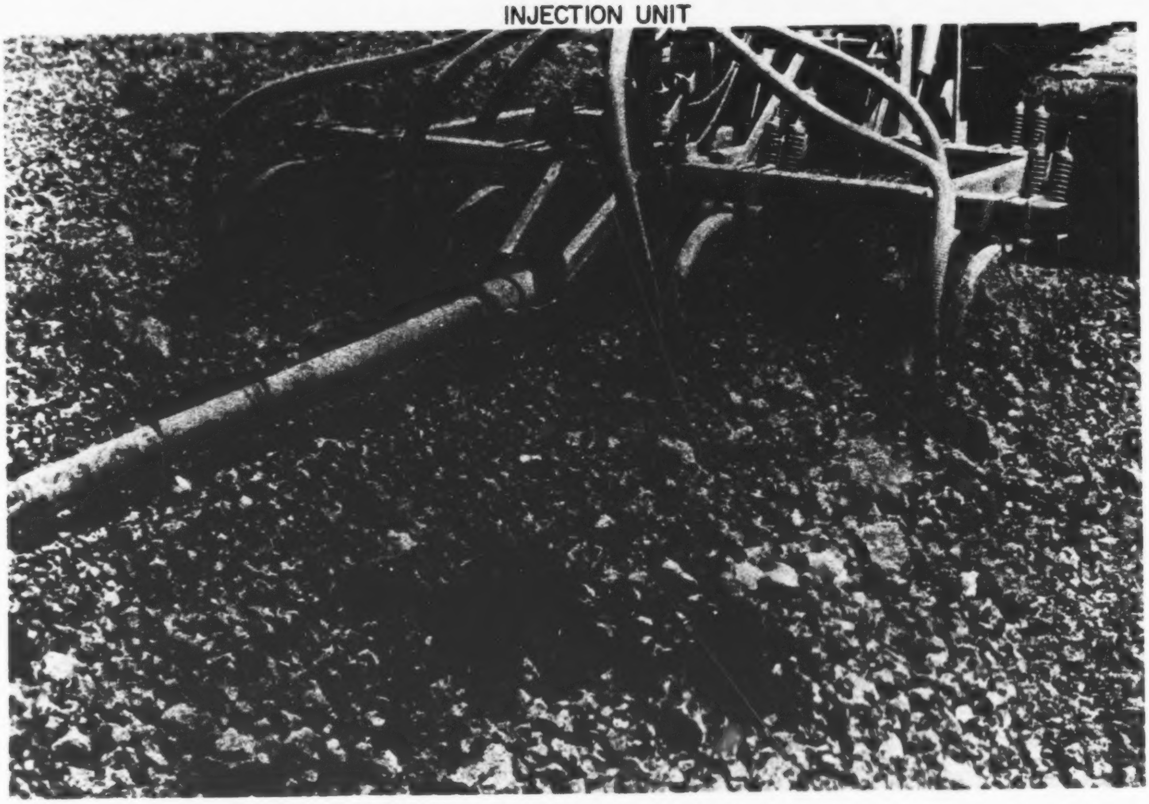


Fig. 3.42 Sludge tractor and injector unit

(From Sewage Sludge Management Program, Wastewater Solids Processing and Disposal, Draft EIR, Sacramento Area Consultants, October, 1978)

APPLICATION RATE. The controlling factor in the rate of sludge application is the nitrogen requirement of the crop. The same assumptions apply to agricultural reclamation as to liquid sludge application rates. The slightly lower nitrogen content (5.9 percent) allows a slightly higher application rate of 3.4 ton (dry weight)/acre/yr (7,600 kg/ha/yr).

METHOD OF APPLICATION. For these rather low rates of sludge application, good control over spreading methods is necessary. Several techniques are discussed briefly in the following paragraphs.

1. *SUBSURFACE INJECTION.* The concentration of solids in the sludge pumped from the storage ponds should be three or four percent to allow pumping of sludge the required distances for umbilical cord injection systems. This also keeps trucking costs down when subsurface injection tankers are used. This would increase costs of operating an injection system. Overall, costs of subsurface injection would be rather high but it would provide a safe, nonodorous application system with excellent control over application rate.
2. *RIDGE AND FURROW OR CONTROLLED FLOODING.* Portable irrigation pipe is often used to take sludge from fixed sludge feeder mains to the actual spreading areas. A 3.4 ton/acre (7,600 kg/ha) sludge application at 3 percent solids concentration would be about 1 inch (2.5 cm) of liquid/sludge mixture. Each spreading area is leveled or managed along contours. Spreading can be done directly from the back of tanker trucks. Sludge is disked into the soil after spreading to minimize odors. Timing and scheduling of sludge application and crop planting must be properly managed.
3. *SLUDGE MIXED WITH IRRIGATION WATER.* This system requires a tie-in between a crop irrigation system and the sludge dredging system. The advantage is that a separate sludge distribution system is unnecessary although there are costs associated with the interties. Sludge application is spread over several irrigation applications depending on the crop type and other factors. This helps to minimize the problem of scheduling sludge applications and crop planting. Disadvantages include the fact that the sludge is not diked into the soil immediately but dries as a layer of sludge cake in the furrows. This may produce additional odors.

3.6212 Permanent Lagoons. This process uses facultative sludge lagoons as described previously for further stabilization and volume reduction prior to transfer to permanent lagoons for disposal. The land used for lagoons is permanently dedicated to the disposal of sludge. Many agencies operate permanent sludge lagoons, sending anaerobically digested sludge directly to them without the intermediate step of long-term storage and stabilization in a facultative pond. These types of lagoons typically have odor problems. To minimize that problem, the facultative pond is sometimes used as a highly controlled intermediate environment to achieve substantial additional volatile solids destruction. An obvious secondary advantage of facultative ponds is their storage capacity which allows transferring sludge to lagoons at the most advantageous times.

Permanent lagoons should be approximately 20 feet (6 m) deep with a 15-foot (4.5 m) working depth. Sludge is permanently stored at an average solids concentration of 12.5 percent and an assumed solids loading of 2,900 tons (dry weight)/acre/yr (6,500,000 kg/ha/yr). Their construction is similar to facultative ponds without the mechanical and piping equipment and electrical connections. Such lagoons have to be located on land dedicated in perpetuity (forever) for that purpose and always maintained with a top cap layer of aerobic liquid to minimize nuisance odors and *VECTOR*[40] problems. Liquid levels are maintained with plant effluent and rainfall. Barriers surrounding the lagoons aid in odor dispersion. Loading is intermittent from facultative ponds.

Permanent lagoons provide additional odor-generation potential. If odors become a problem with the lagoons, surface aeration equipment could be added; however, the increased costs, both capital and operational, are substantial.

3.622 Disposal of Reduced Volume Sludge

3.6220 Composing Process. (Also see Section 3.51.) Most stabilized, dewatered sludge is composted by either of two methods: (a) windrows (Fig. 3.43) or (b) static pile (Fig. 3.44). Both processes require the mixing of freshly dewatered sludge or a bulking material like wood chips or rice hulls to achieve 35 to 40 percent solids content at the start of composting. This solids content is required to allow sufficient voids and air passages for the aerobic composting process to be sustained. Material will be at about 60 percent solids when composting is complete.

Two problems are associated with *WINDROW COMPOSTING:* (1) odors released when windrow is turned and mixed, and (2) improved sludge dewatering resulting in finer solids that make it more difficult to maintain aerobic conditions in the windrow with the same proportion of bulking material. These problems are causing more windrow operators to shift to static pile composting. Temperatures of 60°C are achieved in composting which is considered adequate for removal of pathogens. Temperatures within static piles are usually better controlled than in windrowing.

In a *STATIC PILE* operation, a pug-mill might best be used to achieve a uniform 35 percent solids mixture of dewatered stabilized sludge and bulking material. This mixture is placed in a pile containing 150 to 200 cu yd (115 to 150 cu m). A forced-air system draws air through the pile to a perforated pipe network beneath the pile. Warm, moist air is drawn off and blown through a small pile of previously composted material to reduce odors. The static pile is also covered with a layer of composted material to contain odors. The process takes about 3 weeks to complete. The compost material is then typically stored a month for curing. Open storage may have a slight musty odor. After curing, the material is ready for bulk use or it can be dried further, pulverized and then bagged for sale.

3.6221 Mechanical Drying. Mechanical drying systems usually consist of a cylindrical steel shell that revolves at five to eight rpm. One end of the dryer is slightly higher than the other end. Mechanically dewatered sludge is fed into the higher end. Flights projecting from the inside wall of the shell continually raise the sludge and shower it through the dryer gas, moving the sludge toward the outlet. Dry gas enters the dryer at 1,200°F (650°C) and usually flows in the same direction as the sludge being dried. After the sludge has been rotated in the dryer for 20 to 60 minutes, the dried sludge is discharged at a temperature of 180 to 200°F (82 to 93°C). Exhaust gases are conveyed to a cyclone where entrained solids are separated from the gases. The dried sludge either goes on to further processing or to disposal.

3.6222 Incinerator Ash. On-site landfilling of incinerator ash is accomplished similar to a sanitary landfill and provides good control over disposal of this material. Ash also is disposed of on a dedicated land disposal site as long as it is turned under the soil quickly and not subject to wind action.

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[40] *Vector. An insect or other organism capable of transmitting germs or other agents of disease.*

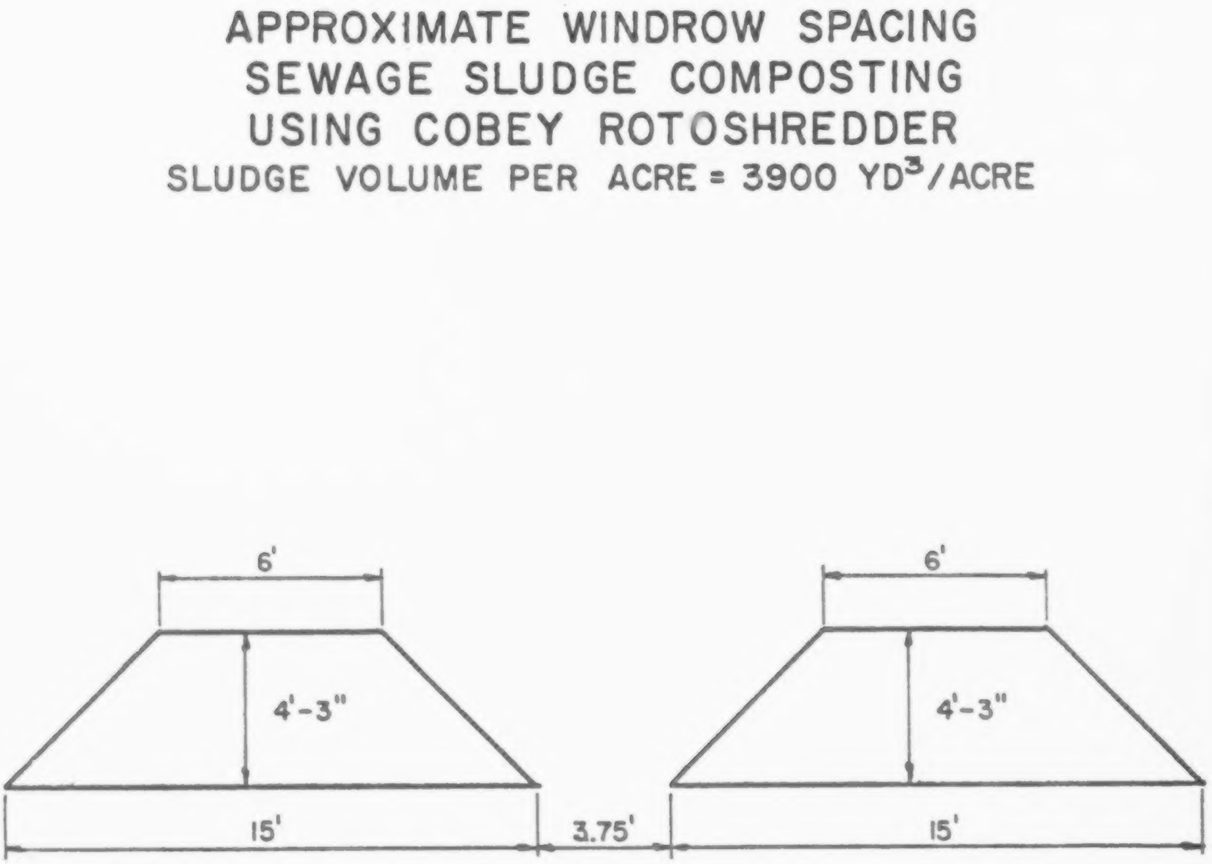
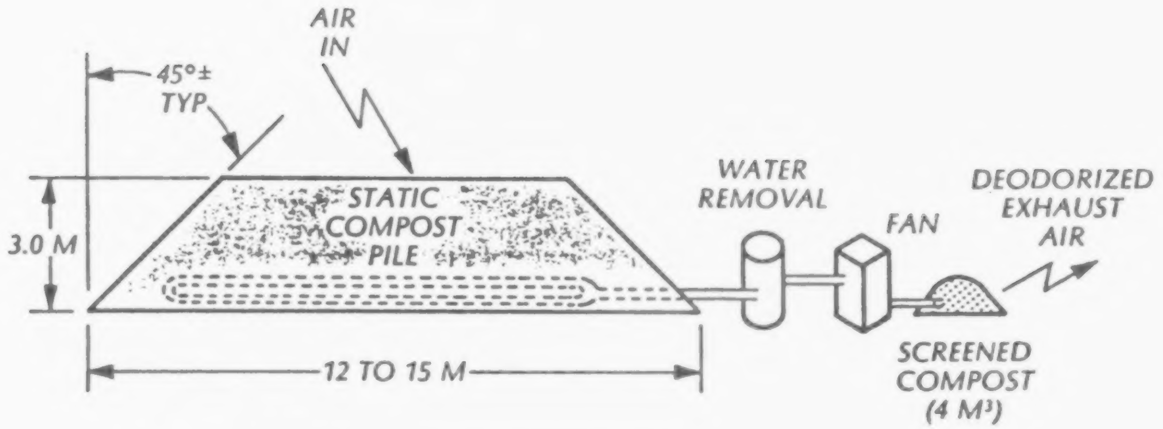
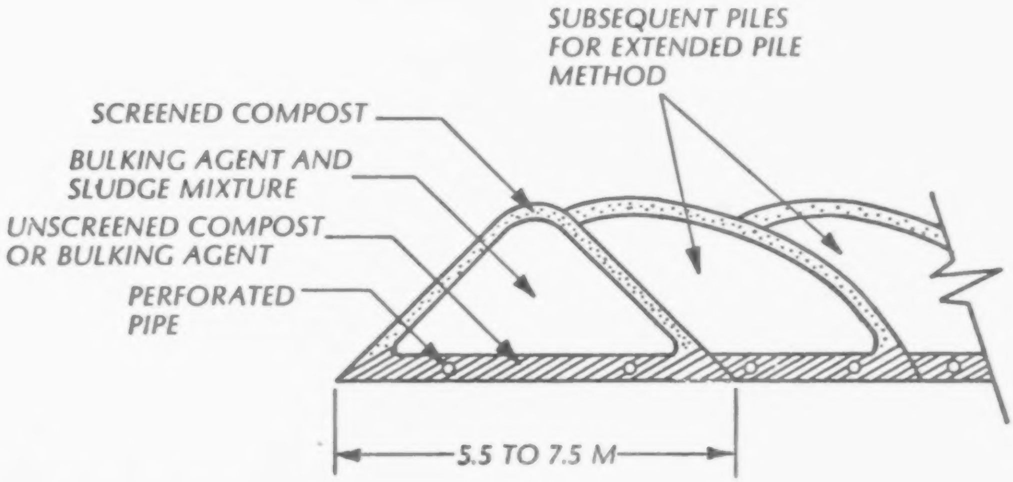

APPROXIMATE WINDROW SPACING
SEWAGE SLUDGE COMPOSTING
USING COBEY ROTOSHREDDER
SLUDGE VOLUME PER ACRE = 3900 YD³/ACRE
6'
6'
4'-3"
4'-3"
15'
3.75'
15'

Fig. 3.43 Approximate windrow spacing


AIR
IN
45°±
TYP
3.0 M
STATIC
COMPOST
PILE
12 TO 15 M
WATER
REMOVAL
FAN
DEODORIZED
EXHAUST
AIR
SCREENED
COMPOST
(4 M^3)

GENERAL LAYOUT


SUBSEQUENT PILES
FOR EXTENDED PILE
METHOD
SCREENED COMPOST
BULKING AGENT AND
SLUDGE MIXTURE
UNSCREENED COMPOST
OR BULKING AGENT
PERFORATED
PIPE
5.5 TO 7.5 M

CROSS SECTION

Fig. 3.44 Typical static compost pile for 40 cubic meters of dewatered sludge

(from EPA Capsule Report, EPA 625/2-77-014)

3.6223 Utilization Options. There are basically three options for use of the composted and mechanically dried materials.

1. Provide a bagged commercial product for sale to the public as a soil amendment.
2. Provide compost for agricultural land use. This would provide more of a marketing problem due to concern over some materials used for bulking: for example, wood chips have nitrogen demand and some tree leaves have toxic effects. Coarse bulking agents, such as wood chips, are usually screened out and reused.
3. Provide compost for nonagricultural land uses. This would include use in parks, golf courses or other recreational areas. There may be only a limited demand for this material due to the established use of high-nitrogen fertilizer on golf courses and turf farms, and the trend to more natural vegetation parks.

3.623 Screenings, Grit and Scum

Screenings, grit and scum are usually the most difficult solids to handle and dispose of because of odor and vector problems.

3.6230 Dewatered Screenings and Grit. Dewatered grit and screenings can be placed in an on-site landfill as long as they are buried the same day as produced to avoid odors.

3.6231 Dewatered Scum. Dewatered scum should be disposed of in a sanitary landfill. Another possibility is the sale of the scum for recovery of grease and other potentially useful byproducts.

3.6232 Dewatered Raw Sludge. Process incinerated ash from dewatered raw sludge the same as incinerated ash from grit, scum and screenings.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.62C How can liquid digested sludge be disposed of?

3.62D How can liquid sludge be spread over land?

3.62E How can composted material be disposed of?

3.62F Why must the surface layer of liquid on permanent lagoons be aerobic?

3.63 Environmental Controls (Monitoring)

The size and nature of the disposal facilities requires that major attention be directed to proper operation and control. Under such conditions, a monitoring program is essential and its elements are described here. An annual report should be issued describing each year's operation and monitoring results. This report is important in communicating with regulatory agencies and local citizens to ensure that problems which develop are being resolved, and in documenting operating results for future enlargements of the system.

The recommended monitoring program for sludge disposal systems is basically a data collection and analysis function aimed at determining if permit conditions, operational and regulatory constraints, and design objectives are being met.

Listed below is a typical recommended monitoring schedule for sludges and other constituents of a liquid dedicated land disposal system with facultative sludge lagoons. Most of this schedule is similar to monitoring that is routinely conducted by treatment plant staff.

Sample Type	Sampling Frequency	Constituents
Raw and thickened sludge (to digesters)	Daily	Flow, TS, VS
Digested sludge (from digesters)	Daily	Flow, TS, VS
Facultative sludge lagoon stored sludge	Quarterly Profiles	TS, VS
Facultative sludge lagoon supernatant layer (each pond)	Every two days	pH, temp, H_2S, DO
Recycled supernatant (total of all ponds)	Daily when operating	TKN, NH_3–N, PO_4–P, COD, BOD, SS, pH

3.630 Odors

The following monitoring is recommended to prevent occurrences of odors and to assess and correct odor problems.

1. Meteorological monitoring for wind machine and general operational control includes the following. It is expected that this information will be continuously recorded.

   Air temperature measurement at 25 feet (7.5 m) and 5 feet (1.5 m) above the ground. This provides data to calculate ΔT which indicates the strength of low-level inversion conditions.

   Wind direction. This is used primarily to calculate the rate of change of wind direction.

   Wind speed measurement.

   These measurements are also necessary to provide a historical record. If and when an odor complaint is recorded at the treatment plant, the meteorology occurring at the time of the problem is available to assist in assessing the problem and correcting it.

2. The best overall odor monitoring program is the number of complaints received from nearby residents. It may be difficult to determine from complaints received which facility was the problem. For this reason, a response team should be available to immediately check on all odor complaints, track them back to the source if possible, and provide a written record. In this manner, problem areas can be identified and solutions undertaken.

   However, in order to avoid problems and determine if the system is operating as intended, odor readings (using an olfactometer as described in Chapter 1, "Odor Control") from the surface of the ponds should be taken periodically, perhaps for three consecutive days during each quarter. Also, odor testing at the ponds should involve qualitative operator judgements recorded daily.

3.631 Sludge/Dedicated Land Disposal Sites

Recommended monitoring of sludge removed from the facultative sludge lagoons is intended mainly for operational purposes, but also to determine if sludge chemical content is compatible with future reuse options. Removed sludge should be monitored for the following:

Sampling Frequency	Constituents
Daily each dredge	TS, Flow
Two composites from each pond dredged/season	Alkalinity, Cl, NH_3-N, Soluble SO_4, TP, TN, Ca, Mg, K, Na, As, Be, Cd, Cr, Cu, Pb, Hg, Mn, Ni, Se, Ag, Zn, PCB 1242, PCB 1254, Technical Chlordane, DDE, TS, VS, pH, EC

Daily records should be made of the location and quantity of sludge spread on the DLD sites. Each DLD site should be sampled in two locations at the end of each spreading season. Soils should be sampled for pH, nitrogen, and heavy metals.

3.632 Groundwater

Potential degrading of groundwater is associated with sludge disposal due to the substantial amount of water (80 to 98 percent) that would be buried with the sludge. This water may travel laterally (side ways) as well as vertically.

Groundwater monitoring wells should be provided around all the disposal facilities. There should be at least four test wells for a DLD site. Two of these should not extend below the confining soil layer and two should extend below this level. The following sampling program should be used for groundwater monitoring wells.

Type	Sampling Frequency	Constituents
Ponds	Quarterly	Alkalinity (phenolphthalein and methyl orange), Cl, TPO_4, hardness (Ca and Mg), pH, TKN, NH_3-N, NO_2-N, organic-N, COD, pH, EC
DLD/Landfill	Annually	Same as above

3.633 Surface Water Monitoring

Surface water runoff which needs to be monitored includes the DLD landfill contaminated runoff, which is designed to be recycled to the plant, as well as any intermittent and continuously flowing surface streams which pass through the plant site. Following the first storm with substantial runoff, a sample of DLD and landfill runoff water should be taken. At two or three other times during the rainy season, additional samples should be taken and analyzed. Runoff constitutents sampled should include the complete list of items analyzed for the plant influent.

Any surface streams which pass through the site require monitoring. These samples should be taken periodically throughout the year. Constituents sampled should include the complete list of items analyzed for plant effluent.

3.634 Public Health Vectors

A variety of disease-causing organisms can be found in untreated wastewater and wastewater solids. These include:

1. Bacteria such as *SALMONÈLLA, SHIGELLA, STREPTOCOCCUS,* and *MYCOBACTERIUM* which are responsible for typhoid and paratyphoid fever, shigellosis, scarlet fever, and tuberculosis.
2. Protozoans and their cysts such as *ENTAMOEBA HISTOLYTICA* which induces amoebic dysentery.
3. Helminths and their ova which include both parasitic and free-living roundworms, flukes, and tapeworms which can infect humans and animals.
4. Viral agents which can infect humans and animals.
5. Viral agents of human and animal origin which can cause infectious hepatitis, polio, meningitis, and a variety of other diseases.

One of the basic goals of wastewater treatment processes is to destroy pathogenic microorganisms. Sludge treatment processes such as anaerobic digestion, incineration, composting and disinfection have variable effectiveness in reducing pathogenic microorganism concentrations.

Stabilization destroys most of the pathogenic organisms. Further destruction is accomplished with composting and further anaerobic digestion in facultative sludge lagoons. When appropriate precautions are taken, plant operators are exposed to an undefinably low level of risk; public exposure and risk are even less.

The potential for the propagation or attraction of birds, rodents, and flies is discussed below briefly.

1. *BIRDS.* Salmonella bacteria are known to be excreted by birds which have fed on food material found in polluted waters. Gull feces have been found to contain *S. TYPHORA* and *S. TYPNI* even after they have been isolated from access to polluted waters. Gulls have been implicated in *SALMONELLA* contamination of a community surface water supply in Alaska after feeding near a wastewater outfall.

   Several species of birds have been observed feeding on floatable materials on facultative sludge lagoons. This is a common occurrence in most wastewater treatment plants which have open basins in which edible organic materials are concentrated. No cases of disease transmission by birds in wastewater treatment plants have been reported. None of the operations discussed pose any public health problems due to birds. The potential aircraft hazard associated with attracting birds to the facultative sludge lagoons is probably minimal. If you find a dead bird, pick it up with a shovel and bury it. You could become infected with lice if you pick up dead birds with your hands.
2. *RODENTS.* Rats, domestic mice, and other rodents which can multiply in response to human activities that create a favorable environment for their survival can serve as vectors for a number of human diseases including leptospirosis, plague, and the dwarf tapeworm *HYMENOLEPIS NANA.* To date (1980), no conditions associated with the five years of operation of facultative sludge lagoons have been observed which contribute to the propagation of rodents. Sludge storage and disposal procedures can be conducted so as to prevent the propagation of rodents.
3. *FLIES.* Flies are a known nuisance and vector of disease which can propagate as a result of certain treatment plant operations or disposal practices. Facultative sludge lagoons have not contributed to fly breeding.

If sanitary landfilling, agricultural reclamation, lagooning, or composting are the disposal or reuse methods, proper management of the processes will minimize fly propagation or attraction. There is no evidence to indicate that anaerobically digested sludge will support fly breeding.

3.64 Acknowledgment

This section was reviewed by Warren Uhte who provided many helpful comments and suggestions.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 260.

3.63A What items should be measured in an odor-monitoring program?

3.63B How many and where should the groundwater monitoring wells be located for a dedicated land disposal (DLD) site?

3.7 REVIEW OF PLANS AND SPECIFICATIONS

On occasion, operators will be asked to review and comment on design drawings and specifications. Engineering drawings generally contain much detail and can be rather complicated to understand. When you are asked to review design drawings, you should be concerned with those features that will directly affect day-to-day operation, routine maintenance and periodic repairs.

Day-to-day operation, maintenance and repairs are affected by effort(s) required to open and close valves; read meters; lubricate equipment; repair pumps and drive motors; replace equipment such as chains, sprockets, and bearings; unclog and clean pipes and float control mechanisms, and wash down the area.

Regardless of the equipment or process being installed, the operator should be sure that the following provisions are incorporated into the design:

1. All valves are easily accessible and enough area is provided to facilitate turning of the valves;
2. All meters and gages are easily readable and located where process adjustments can be made if so indicated by the meters and gages;
3. Sufficient area is provided around pumps and drives to facilitate routine maintenance and repairs; and
4. Sufficient area, wash water capacity and drains are provided around major pieces of equipment such as thickeners and centrifuges to facilitate repairs and clean up operations.

In general, the operator needs to sit back and reflect on those items or situations from past experience that caused trouble with daily operating and routine maintenance tasks. The operator has to contend with the system(s) or unit processes being installed and if given the opportunity to provide input into the final design, you should take full advantage of ensuring that equipment is accessible and enough working area is provided.

When reviewing plans and specifications, you must consider what you will do if each particular treatment process breaks down. You have to decide where to store the sludge and how long you might have to store it. For example, if you have centrifuges to thicken the sludge and then burn the sludge in an incinerator, what will you do if the incinerator is out of service? Can the sludge be hauled to a sanitary landfill? How many truck loads would have to be hauled per day? Where would the sludge be stored while the truck is traveling to and from the dump? These are the types of questions the operator must answer, because they are the problems you will have to solve when equipment fails. Simple alterations in the design before facilities are built can make problems caused by equipment failures easier to solve.

Specific areas of concern for the unit processes described in this chapter are summarized in Table 3.26.

QUESTION

Write your answer in a notebook and then compare your answer with the one on page 260.

3.7A List the important items you would consider when reviewing plans and specifications.

END OF LESSON 5 OF 5 LESSONS
ON
SLUDGE HANDLING & DISPOSAL

TABLE 3.26 SPECIFIC O & M ITEMS CONSIDERED WHEN REVIEWING PLANS AND SPECIFICATIONS

UNIT PROCESS	RECOMMENDED PROVISIONS
Gravity Thickening	1. Sludge collectors and surface scrapers are equipped with variable-speed motors.
	2. Sludge withdrawal line is at *LEAST 4 INCHES* (10 cm) in diameter and valves are provided on the suction side and discharge side of the sludge withdrawal pump.
	3. A Tee with a valve is provided between the suction valve described in Item 2 and the sludge outlet to facilitate backflushing in the event of clogging.
	4. A valve is provided on the suction side and discharge side of the influent sludge pump.
	5. Sample taps and valves are provided on the influent, effluent and sludge withdrawal lines to facilitate sample collection.
Dissolved Air Flotation	1. Surface and bottom sludge collectors are equipped with variable-speed motors.
	2. Same as Item 2, Gravity Thickening.
	3. Same as Item 3, Gravity Thickening.
	4. Same as Item 4, Gravity Thickening.
	5. Same as Item 5, Gravity Thickening.
	6. A sight glass is provided on the retention tank.
	7. Level indicators in the retention tank are accessible for cleaning or repairs.
Centrifugation and Filtration	1. Sludge hoppers are provided with moveable catch troughs to collect and divert wash water to a common drain.
	2. A wash water supply and drains are provided in the area of sludge conveyors to facilitate cleaning operations.
	3. A permanent wash water line and valve are provided on the influent to the unit.
	4. Same as Item 4, Gravity Thickening.
	5. Same as Item 5, Gravity Thickening.

Chemical Conditioning

1. Dry chemical feeders are equipped with Infra-red heating lamps to prevent the absorption of moisture.
2. An eductor-type dry chemical feeder is provided to serve as standby for automatic feeders.
3. A bulk storage tank is provided for liquid chemicals.
4. Chemical feed pumps are equipped with variable-speed motors.
5. The walking areas around chemical systems are coated with a non-skid type paint.

Thermal Conditioning

1. A water softener is provided where appropriate to remove hardness from the boiler make-up water. Also provisions to de-aerate the water.
2. An acid resistent flushing system should be incorporated for acid washing of reactors and heat exchangers.
3. Sample taps and valves should be provided on the influent, high-rate, and decant overflow and underflow lines.
4. The decant tank should be totally enclosed and equipped with a vent fan.
5. Gas scrubbers and/or carbon absorbers be provided to clean the vent gases.
6. Same as Item 2, Gravity Thickening.
7. Same as Item 3, Gravity Thickening.
8. Same as Item 4, Gravity Thickening.

3.8 ADDITIONAL READING

1. *LAND APPLICATION OF SLUDGE.* Obtain from National Environmental Training Allocation, 8687 Via de Ventura, Suite 214, Phoenix, Arizona 85258. Price $14.50 members, $18.00 nonmembers.
2. *SLUDGE DEWATERING,* MOP 20. Obtain from Publications Order Department, Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994. Order No. M0016OHO. Price $24.00 member, $32.00 nonmembers.
3. *SLUDGE STABILIZATION,* MOP FD-9. Obtain from Publications Order Department, Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994. Order No. MFD9OHO. Price $24.00 members, $32.00 nonmembers.
4. *SLUDGE THICKENING,* MOP FD-1. Obtain from Publications Order Department, Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994. Order No. MFD1OHO. Price $12.00 members, $16.00 nonmembers.

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. SLUDGE HANDLING AND DISPOSAL

(Lesson 5 of 5 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 4.

25. Why are chemically stabilized and wet oxidized sludges generally not suited for compost operations?
26. How would you determine the frequency of turning compost stacks?
27. How does incineration reduce the volume of sludge?
28. Where should air be added to the furnace for proper combustion?
29. How can you tell by looking at the flames in the burning zone how much air is present?
30. What happens if the incinerator shaft speed is too high or too slow?
31. Why should the disposal or utilization of sludge from digesters without additional treatment be avoided?
32. What are the main reasons for using wastewater solids for agricultural purposes?
33. What are the advantages of using trucks to spread digested sludge in an agricultural reclamation project?

PLEASE WORK THE OBJECTIVE TEST NEXT.

SUGGESTED ANSWERS

Chapter 3. Sludge Handling and Disposal

Answers to questions on pages 126 and 127.

3.0A The two types of sludges produced at a wastewater treatment facility are primary sludge and secondary sludge. Primary sludge includes all the solids which settle to the bottom of the primary sedimentation basin and are removed from the waste stream. Primary sludges are usually fairly coarse and fibrous, have specific gravities greater than water and are composed of 70 to 80 percent volatile matter. Secondary sludge is generated as a by-product of biological degradation of organic wastes. Secondary sludges are finer than primary sludge solids, less fibrous, have specific gravities closer to that of water, and consist of 75 to 80 percent volatile matter.

3.0B Volumes of primary sludge depend on inflow, influent suspended solids, and efficiency of the primary sedimentation basin.

3.0C

Known		Unknown
Flow, MGD	= 2.0 MGD	Sludge, lbs/day
Influent SS, mg/*L*	= 200 mg/*L*	
Effluent SS, mg/*L*	= 120 mg/*L*	

Determine the quantity of primary sludge in pounds per day.

$$\begin{aligned}\text{Primary Sludge, lbs/day} &= \text{Flow, MGD} \times (\text{Infl SS, mg}/L - \text{Effl. SS mg}/L) \times 8.34 \text{ lbs/gal}\\ &= 2.0 \text{ MGD} \times (200 \text{ mg}/L - 120 \text{ mg}/L) \times 8.34 \text{ lbs/gal}\\ &= 2.0 \text{ MGD} \times 80 \text{ mg}/L \times 8.34 \text{ lbs/gal}\\ &= 1{,}335 \text{ lbs/day}\end{aligned}$$

3.0D Variables that influence the production of secondary sludges include the flow to the biological system, the BOD loading to the biological system, the efficiency of the biological system in removing BOD, and the growth rate of the bacteria in the system.

3.0E

Known		Unknown
Flow, MGD	= 2.0 MGD	Sec. Sludge, lbs/day
Sec. Infl BOD, mg/*L*	= 180 mg/*L*	
Sec. Effl BOD, mg/*L*	= 30 mg/*L*	

Growth Rate, Y, $\dfrac{\text{lbs SI}}{\text{lb BOD rem}} = \dfrac{0.5 \text{ lbs sludge}}{1 \text{ lb BOD removed}}$

Estimate quantity of secondary sludge in pounds per day.

$$\begin{aligned}\text{Sec. Sludge, lbs/day} &= \text{Flow, MGD} \times (\text{Infl BOD, mg}/L - \text{Effl Bod, mg}/L) \times 8.34 \text{ lbs/gal} \times \frac{0.5 \text{ lbs sludge}}{1 \text{ lb BOD removed}}\\ &= 2.0 \text{ MGD} \times (180 \text{ mg}/L - 30 \text{ mg}/L) \times 8.34 \text{ lbs/gal} \times 0.5\\ &= 1{,}251 \text{ lbs/day}\end{aligned}$$

3.0F

Known		Unknown
Conditions in Problem 3.0C		Sludge, gal/day
Sludge, lbs/day	= 1335 lbs/day	
Susp Solids, %	= 4.0%	

Estimate the primary sludge volume in gallons per day.

$$\begin{aligned}\text{Sludge, gal/day} &= \frac{\text{Sludge, lbs/day}}{8.34 \text{ lbs/gal} \times (\text{Solids, \%}/100\%)}\\ &= \frac{1335 \text{ lbs/day}}{8.34 \text{ lbs/gal} \times (4.0\%/100\%)}\\ &= 4{,}002 \text{ gallons/day}\end{aligned}$$

Answers to questions on page 131.

3.10A The primary function of sludge thickening is to reduce the sludge volume to be handled in subsequent processes.

3.10B

Known		Unknown
Sec. Sludge, gal/day	= 12,000 gal	Dry Sludge, lbs/day
Solids Conc., %	= 1.0%	

Determine the amount of dry sludge in pounds per day.

$$\begin{aligned}\text{Dry Sludge, lbs/day} &= \text{Sludge, gal/day} \times 8.34 \text{ lbs/gal} \times \frac{\text{Solids Conc., \%}}{100\%}\\ &= 12{,}000 \text{ gal/day} \times 8.34 \text{ lbs/gal} \times \frac{1\%}{100\%}\\ &= 12{,}000 \text{ gal/day} \times 8.34 \text{ lbs/gal} \times 0.01\\ &= 1{,}000 \text{ lbs/day}\end{aligned}$$

3.10C

Known		Unknown
Sec. Sludge, lbs/day	= 1000 lbs/day	Sludge Volume, gal/day
Solids Conc., %	= 1.5%	

Determine sludge volume in gallons per day.

$$\begin{aligned}\text{Sludge Vol, gal/day} &= \frac{\text{Sec. Sludge, lbs/day}}{8.34 \text{ lbs/gal} \times \dfrac{\text{Solids Conc., \%}}{100\%}}\\ &= \frac{1000 \text{ lbs/day}}{8.34 \text{ lbs/gal} \times \dfrac{1.5\%}{100\%}}\\ &= 8{,}000 \text{ gal/day}\end{aligned}$$

Answers to questions on page 136.

3.11A Main components of gravity thickeners include:

1. Inlet and distribution assembly,
2. Sludge rake,
3. Vertical steel members or "pickets" mounted on the sludge rake,
4. Effluent or overflow weir, and
5. Scum removal equipment.

3.11B 1. The inlet baffle causes the influent to flow downward towards the bottom of the tank where the solids settle. The inlet baffle provides for an even distribution of sludge throughout the tank and reduces the possibility of short-circuiting to the effluent end of the thickener.

2. Sludge rakes cause the settled sludge to move towards the center of the tank to be removed by a sludge pump.

3. The vertical pickets provide for gentle stirring of the settled sludge as the rake rotates. This gentle stirring action opens up channels for the vertical release of entrapped gases and free moisture which promotes or enhances the concentration of the settled sludge.

3.11C The age of the sludge to be thickened is very important. Fresh primary sludge usually can be concentrated to the highest degree. If gasification occurs due to anaerobic conditions, sludges are difficult to thicken. Secondary sludges are not as well suited for gravity thickening as primary sludge. Secondary sludges contain large quantities of "bound" water which renders the sludge less dense than primary sludge solids.

3.11D As the temperature of the sludge (primary or secondary) increases, the rate of biological activity increases and the sludge tends to gasify and rise at a higher rate. During summer time operation, the settled sludge has to be removed at a faster rate from the thickener than during winter time operation when the sludge temperature is lower and biological activity and subsequent gas production proceeds at a slower rate.

3.11E

Known	**Unknown**
Diameter, ft = 30 ft	Hydraulic Surface Loading, gpd/sq ft
Sludge Solids, % = 3%	Solids Loading, lbs/day/sq ft.
Flow, GPM = 60 GPM	

Determine the water surface area.

$$\text{Surface Area, sq ft} = \frac{\pi}{4}(\text{Diameter, ft})^2$$
$$= 0.785\,(30\text{ ft})^2$$
$$= 707\text{ sq ft}$$

Calculate the hydraulic surface loading.

$$\text{Hydraulic Surface Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}}$$
$$= \frac{60\text{ gal/min} \times 1440\text{ min/day}}{707\text{ sq ft}}$$
$$= 122\text{ gpd/sq ft}$$

Determine the solids applied to the thickener, lbs/day.

$$\text{Solids Applied, lbs/day} = \text{Flow, gpd} \times 8.34\text{ lbs/day} \times \frac{\text{Solids, \%}}{100\%}$$
$$= 60\text{ gal/min} \times 1440\text{ min/day} \times 8.34\text{ lbs/gal} \times \frac{3\%}{100\%}$$
$$= 21{,}617\text{ lbs/day}$$

Calculate the solids loading.

$$\text{Solids Loading, lbs/day/sq ft} = \frac{\text{Solids Applied, lbs/day}}{\text{Surface Area, sq ft}}$$
$$= \frac{21{,}617\text{ lbs/day}}{707\text{ sq ft}}$$
$$= 31\text{ lbs/day/sq ft}$$

3.11F

Known		**Unknown**
Flow, GPM	= 40 GPM	Suspended Solids Removal Eff., %
WAS Conc., %	= 0.9%	
, mg/L	= 9,000 mg/L	Concentration Factor
Underflow Sludge, %	= 3%	
Eff. Susp. Sol., mg/L	= 1,800 mg/L	

Calculate the suspended solids removal efficiency,%.

$$\text{Efficiency, \%} = \frac{(\text{Infl., mg}/L - \text{Effl., mg}/L) \times 100\%}{\text{Inf., mg}/L}$$
$$= \frac{(9{,}000\text{ mg}/L - 1{,}800\text{ mg}/L) \times 100\%}{9{,}000\text{ mg}/L}$$
$$= 80\%$$

Determine the concentration factor.

$$\text{Concentration Factor} = \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}}$$
$$= \frac{3.0\%}{0.9\%}$$
$$= 3.33$$

Answers to questions on page 140.

3.11G Routine visual checks on gravity thickeners as well as other equipment help the operator identify equipment malfunctions and/or decreases in process efficiency.

3.11H The term "hole" or coning refers to a cone-shaped hole that can develop in the sludge blanket which allows liquid from above the sludge blanket (rather than sludge from the sludge blanket) to be pumped from the thickener. A hole in the sludge blanket can best be corrected by lowering the flow to the thickener, increasing the speed of the collectors to keep the sludge at the point of withdrawal and decreasing the rate of underflow sludge pumping.

3.11I Possible causes of solids rising to the surface:

1. Gasification,
2. Septic feed,
3. Blanket disturbances,
4. Chemical inefficiencies, and
5. Excessive loadings.

Procedures to correct the problem(s):

1. Increase sludge withdrawal rate,
2. Increase sludge pumping from clarifier,
3. Lower collector speed,
4. Increase chemical feed rate, and
5. Lower flow if possible.

Answers to questions on page 145.

3.12A The main components of dissolved air flotation (DAF) units are: (1) air injection equipment, (2) agitated or unagitated pressurized retention tank, (3) recycle pump, (4) inlet or distribution assembly, (5) sludge scrapers, and (6) an effluent baffle.

3.12B
1. The function of the distribution box is to allow the air to come out of solution in the form of minute air bubbles which attach to the solids and cause them to rise to the surface.
2. The retention tank provides a location to dissolve air into the liquid.
3. The effluent baffle is provided to keep the floated solids from contaminating the effluent.

3.12C A sight glass should be provided to periodically check the level of the air-liquid interface because on occasion the float mechanisms may fail and the retention tank will either fill completely with liquid or fill completely with air.

3.12D The performance of DAF thickeners depends on (1) type and age of the feed sludge, (2) solids and hydraulic loading, (3) air to solids (A/S) ratio, (4) recycle rate, and (5) sludge blanket depth.

3.12E The age of the sludge usually does not affect flotation performance as drastically as it affects gravity concentrators. A relatively old sludge has a natural tendency to float due to gasification and this natural buoyancy will have little or no adverse effects on the operation of flotation thickeners.

3.12F

Known	Unknown
Diameter, ft = 20 ft	Hydraulic Surface Loading, gpd/sq ft
Flow, GPM = 100 GPM	

Determine the liquid surface area, sq ft.

$$\text{Surface Area, sq ft} = \frac{\pi}{4} \times (\text{Diameter, ft})^2$$

$$= 0.785 \times (20\text{ ft})^2$$

$$= 314\text{ sq ft}$$

Calculate the hydraulic surface loading, gpd/sq ft.

$$\text{Surface Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}}$$

$$= \frac{100\text{ gal/min} \times 1440\text{ min/day}}{314\text{ sq ft}}$$

$$= 458\text{ gpd/sq ft}$$

3.12G

Known	Unknown
Same as problem 22.12F	Solids Loading, lbs/day/sq ft
Influent Sludge, % = 0.75	
, mg/L = 7,500 mg/L	A/S Ratio, lb air/lb solids
Influent Sludge	Recycle Flow Rate, GPM
Flow, cfm = 2.5 cu ft/min	
Air, cfm = 0.75 cu ft/min	
Recycle Ratio, % = 100%	

Determine solids applied, lbs/day.

$$\text{Solids Applied, lbs/day} = \text{Flow, }\frac{\text{cu ft}}{\text{min}} \times \frac{1440\text{ min}}{\text{day}} \times \frac{62.4\text{ lbs}}{\text{cu ft}} \times \frac{\text{SS, \%}}{100\%}$$

$$= 2.5\ \frac{\text{cu ft}}{\text{min}} \times \frac{1440\text{ min}}{\text{day}} \times \frac{62.4\text{ lbs}}{\text{cu ft}} \times \frac{0.75\%}{100\%}$$

$$= 1{,}685\text{ lbs/day}$$

Calculate solids loading, lbs/day/sq ft.

$$\text{Solids Loading, lbs/day/sq ft} = \frac{\text{Solids Applied, lbs/day}}{\text{Surface Area, sq ft}}$$

$$= \frac{1{,}685\text{ lbs/day}}{314\text{ sq ft}}$$

$$= 5.4\text{ lbs/day/sq ft}$$

Determine the air supply in pounds per hour.

$$\text{Air Supply, lbs/hr} = \text{Air Flow, }\frac{\text{cu ft}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times \frac{0.075\text{ lbs air}}{\text{cu ft}}$$

$$= 0.75\ \frac{\text{cu ft}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times \frac{0.075\text{ lbs}}{\text{cu ft}}$$

$$= 3.375\text{ lbs/hr}$$

Determine the solids applied in pounds per hour.

$$\text{Solids Applied, lbs/hr} = \frac{\text{Solids Applied, lbs/day}}{24\text{ hr/day}}$$

$$= \frac{1685\text{ lbs/day}}{24\text{ hr/day}}\text{(from 22.20D)}$$

$$= 70.2\text{ lbs/hr}$$

Calculate the pounds of air to pounds of solids (A/S) ratio.

$$\frac{\text{Air, lbs}}{\text{Solids, lbs}} = \frac{\text{Air Supply, lbs/hr}}{\text{Solids Applied, lbs/hr}}$$

$$= \frac{3.375\text{ lbs air/hr}}{70.2\text{ lbs solids/hr}}$$

$$= 0.05\text{ lbs air/lb solids}$$

Determine the recycle flow, GPM.

$$\text{Recycle Flow, GPM} = \text{Inflow, GPM} \times \frac{\text{Recycle Ratio, \%}}{100\%}$$

$$= 2.5\ \frac{\text{cu ft}}{\text{min}} \times \frac{7.5\text{ gal}}{\text{cu ft}} \times \frac{100\%}{100\%}$$

$$= 18.8\text{ GPM}$$

or = 19 GPM for pumping rate

3.12H

Known		**Unknown**
DAF Unit		SS Removal Eff., %
Infl. Sludge, %	= 1.0%	Concentration Factor
, mg/L	= 10,000 mg/L	
Effl. Sludge, % (Thickened Sludge)	= 3.8%	
Effl. Liquid SS, mg/L	= 50 mg/L	

Determine the suspended solids removal efficiency.

$$\text{SS Efficiency, \%} = \frac{(\text{SS Inf., mg/}L - \text{SS Eff., mg/}L)}{\text{SS Inf., mg/}L} \times 100\%$$

$$= \frac{(10{,}000\text{ mg/}L - 50\text{ mg/}L)}{100{,}000\text{ mg/}L} \times 100\%$$

$$= 99.5\%$$

Determine the concentration factor for the thickened sludge.

$$\text{Concentration Factor, (cf)} = \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}}$$

$$= \frac{3.8\%}{1.0\%}$$

$$= 3.8$$

Answers to questions on page 146.

3.12I *PROBLEM.* Poor effluent quality (high suspended solids) and thinner than normal sludge.

Possible Causes	**Possible Solutions**
a. A/S low.	a. Increase air input. Repair and/or turn on compressor.
b. Pressure too low or too high.	b. Repair and/or turn on compressor.
c. Recycle pump inoperative.	c. Turn on recycle pump.
d. Reaeration pump inoperative.	d. Turn on reaeration pump.
e. Chemical addition inadequate.	e. Increase dosage.
f. Loading excessive.	f. Lower flow rate.

Answers to questions on page 156.

3.13A Three centrifuge designs commercially available today are (1) basket centrifuges, (2) scroll centrifuges, and (3) disc-nozzle type centrifuges. Basket centrifuges operate in a batch mode, while scroll and disc-nozzle type operate continuously.

3.13B Centrifugal thickening is affected by (1) type and age of the feed sludge, (2) solids and hydraulic loading, (3) bowl speed and resulting gravitational ("g") forces, (4) pool depth and differential scroll speed for scroll centrifuges, and (5) size and number of nozzles for disc centrifuges.

3.13C Centrifuges are not commonly used to thicken primary sludges because they have inlet assemblies that are highly subject to clogging.

3.13D

Known		**Unknown**
20 in × 60 in scroll centrifuge		Hydraulic Loading, gal/hr
Feed Rate, GPM	= 30 GPM	Solids Loading, lbs/hr
Infl. Solids, %	= 1.1%	
, mg/L	= 11,000 mg/L	

Calculate the hydraulic loading in gallons per hour.

$$\text{Hydraulic Load, gal/hr} = \text{Flow, GPM} \times 60\text{ min/hr}$$

$$= 30\text{ gal/min} \times 60\text{ min/hr}$$

$$= 1{,}800\text{ gal/hr}$$

Calculate the solids loading in pounds of solids per hour.

$$\text{Solids Load, lbs/hr} = \text{Flow, gal/hr} \times 8.34\text{ lbs/gal} \times \frac{\text{SS, \%}}{100\%}$$

$$= 1800\text{ gal/hr} \times 8.34\text{ lbs/gal} \times \frac{1.1\%}{100\%}$$

$$= 165\text{ lbs solids/hr}$$

3.13E

Known		**Unknown**
48-inch diameter basket centrifuge		Hydraulic Loading, gal/hr
Feed Rate, GPM	= 30 GPM	Solids Loading, lbs/hr
Infl. Solids, %	= 1.1%	
, mg/L	= 11,000 mg/L	
Feed Time, Min	= 25 min	
Down Time, Min	= 3 min	

Calculate the hydraulic loading in gallons per hour.

$$\text{Hydraulic Load, gal/hr} = \text{Flow, GPM} \times \frac{60\text{ min}}{\text{hr}} \times \frac{\text{Run Time, min}}{(\text{Run, min} + \text{Down, min})}$$

$$= 30\,\frac{\text{gal}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times \frac{25\text{ min}}{(25\text{ min} + 3\text{ min})}$$

$$= 30 \times 60 \times \frac{25}{28}$$

$$= 1{,}607\text{ gal/hr}$$

Calculate the solids loading in pounds of solids per hour.

$$\text{Solids Load, lbs/hr} = \text{Hyd. Load, }\frac{\text{gal}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%}$$

$$= 1{,}607\,\frac{\text{gal}}{\text{hr}} \times 8.34\,\frac{\text{lbs}}{\text{gal}} \times \frac{1.1\%}{100\%}$$

$$= 147\text{ lbs solids/hr}$$

3.13F As the differential scroll speed is increased, the solids that are compacted on the bowl wall are conveyed out of the centrifuge at a faster rate, resulting in a decrease in the concentration of these solids. Lower concentrations result because as the solids are moved out at a faster rate they are subjected to centrifugal forces for shorter periods of time.

3.13G

Known		**Unknown**
20-inch diameter disc centrifuge		Efficiency, %
Flow, GPM	= 25 GPM	Concentration Factor, (cf)
Infl. SS, %	= 0.65%	
, mg/L	= 6,500 mg/L	
Effl, SS, %	= 0.03%	
, mg/L	= 300 mg/L	
Thick. Sl, %	= 4.9%	
, mg/L	= 49,000 mg/L	

Calculate the efficiency of the disc centrifuge.

$$\text{Efficiency, \%} = \frac{(\text{Infl. SS, mg}/L - \text{Effl. SS, mg}/L) \times 100\%}{\text{Infl. SS, mg}/L}$$

$$= \frac{(6500 \text{ mg}/L - 300 \text{ mg}/L) \times 100\%}{6500 \text{ mg}/L}$$

$$= 95.4\%$$

Determine the concentration factor for the thickened sludge.

$$\text{Concentration Factor (cf)} = \frac{\text{Thickened Sludge Concentration, \%}}{\text{Influent Sludge Concentration, \%}}$$

$$= \frac{4.9\%}{0.65\%}$$

$$= 7.5$$

Answers to questions on page 158.

3.13H *PROBLEM:* Scroll centrifuge has poor centrate quality, but discharge solids are good.

Check	Possible Solutions
1. Scroll rpm	1. Increase scroll speed
2. Flow rate	2. Decrease flow
3. Pool setting	3. Increase pool
4. Chemical system	4. Increase chemical dosage

3.13I The concentration of thickened sludge from a disc centrifuge can be increased by decreasing the number and/or size of the nozzles. These changes problably would have no effect on the centrate quality.

END OF ANSWERS
TO QUESTIONS
IN LESSON
1

Answers to questions on page 164.

3.20A The goals of stabilization are to convert the volatile (organic) or odor-causing portion (fraction) of the sludge solids to nonodorous end products, to prevent the proliferation (breeding) of insects upon disposal and to reduce the pathogenic (disease-carrying) organism content.

3.20B Unit processes commonly used for sludge stabilization include: (1) anaerobic digestion, (2) aerobic digestion, and (3) chemical treatment.

3.21A In the two-step process of anaerobic digestion, first, facultative acid-forming organisms convert complex organic matter to volatile (organic) acids. Next, the anaerobic methane-forming organisms convert the acids to odorless end products of methane gas and carbon dioxide.

3.22A In the aerobic digestion process, thickened sludge is fed to the digester inlet. Air from blowers is diffused into the digester to provide oxygen for the organisms and to cause mixing of the digester contents. Digested sludge exists through an effluent line and is either pumped directly to dewatering facilities or to a gravity thickener prior to dewatering.

3.22B Continuous feeding of aerobic digesters is preferred over batch draw-and-fill systems because continuous operation tends to minimize operator attention and to reduce associated operational costs.

3.22C Factors affecting aerobic digesters include (1) sludge type, (2) digestion time, (3) digestion temperature, (4) volatile solids loading, (5) quantity of air supplied, and (6) dissolved oxygen concentrations within the digester.

3.22D Aerobic digestion is more suitable for treating secondary sludges than primary sludges because these sludges are composed primarily of biological cells that are produced in the activated sludge and/or trickling filter processes as a by-product of degrading organic matter. In the absence of food, these microorganisms enter the endogenous or death phase of their life cycle. When no food is available, the biomass begins to self-metabolize (self-destruct), which results in a conversion of the biomass to end products of carbon dioxide and water and a net decrease in the sludge mass.

3.22E The operator can control digestion time by controlling the degree or sludge thickening prior to digestion. The thicker the sludge, the longer the digestion time.

3.22F

Known	Unknown
Digester Volume, cu ft = 140,000 cu ft	Digestion Time, days
Flow, gpd = 110,000 gpd	

Calculate the digester volume in gallons.

$$\text{Digester Volume, gal} = \text{Digester Volume, cu ft} \times 7.48 \text{ gal/cu ft}$$

$$= 140{,}000 \text{ cu ft} \times 7.48 \text{ gal/cu ft}$$

$$= 1{,}047{,}200 \text{ gallons}$$

Determine the digestion time in days.

$$\text{Digestion Time, days} = \frac{\text{Digester Volume, gallons}}{\text{Flow, gpd}}$$

$$= \frac{1{,}047{,}200 \text{ gallons}}{110{,}000 \text{ gpd}}$$

$$= 9.5 \text{ days}$$

3.22G

Known	Unknown
Known for problem 22.22F	New Digestion Time, days
Increase thickened sludge from 2.7 to 3.5 percent solids	
Digestion Time, 9.5 days	

Calculate the new digestion time in days.

$$\text{Digestion Time, days} = \frac{\text{Old Digestion Time, days} \times \text{New Thickened Solids, \%}}{\text{Old Thickened Solids, \%}}$$

$$= \frac{9.5 \text{ days} \times 3.5\%}{2.7\%}$$

$$= 12.3 \text{ days}$$

3.22H Desirable aerobic digestion temperatures are approximately (65 to 80°F). As the temperature decreases from desirable temperatures, the rate of biological activity decreases.

3.22I

Known		Unknown
Aerobic Digester		Digestion Time, days
Dimensions, ft		VSS Loading, lbs/day/cu ft
L	= 120 ft	
W	= 25 ft	
SWD	= 11 ft	
Flow, gpd	= 24,000 gpd	
Sludge Solids, %	= 3.1%	
Volatile Matter, %	= 73%	

Calculate the aerobic digester volume in cubic feet and gallons.

$$\text{Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{SWD, ft}$$
$$= 120 \text{ ft} \times 25 \text{ ft} \times 11 \text{ ft}$$
$$= 33{,}000 \text{ cu ft}$$

$$\text{Volume, gal} = 33{,}000 \text{ cu ft} \times 7.48 \text{ gal/cu ft}$$
$$= 246{,}840 \text{ gallons}$$

Determine the digestion time in days.

$$\text{Digestion Time, days} = \frac{\text{Digester Volume, gal}}{\text{Flow, gpd}}$$
$$= \frac{246{,}840 \text{ gallons}}{24{,}000 \text{ gpd}}$$
$$= 10.3 \text{ days}$$

Calculate the VSS applied in pounds of volatile matter per day.

$$\text{VSS Applied, lbs/day} = \text{Flow, gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%} \times \frac{\text{VM, \%}}{100\%}$$
$$= 24{,}000 \text{ gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{3.1\%}{100\%} \times \frac{73\%}{100\%}$$
$$= 4{,}530 \text{ lbs VSS/day}$$

Determine the VSS loading in pounds per day per cubic foot.

$$\text{VSS Loading, lbs/day/cu ft} = \frac{\text{VSS Applied, lbs/day}}{\text{Digester Volume, cu ft}}$$
$$= \frac{4530 \text{ lbs VSS/day}}{33{,}000 \text{ cu ft}}$$
$$= 0.14 \text{ lbs VSS/day/cu ft}$$

3.22J DO in aerobic digesters should be maintained at concentrations greater than 1.0 mg/*L* to avoid the growth of filamentous organisms which can lead to sludge bulking and/or foaming.

3.22K DO is measured in aerobic digesters by lowering a DO probe into the digester, gently raising and lowering the probe 6 to 12 inches and recording the readout measurement after the readout has stabilized.

3.22L

Known	Unknown
O_2 Uptake Data	O_2 Uptake Rate, mg/*L*/hr

Calculate the O_2 uptake rate in mg/*L*/hr.

$$O_2 \text{ Uptake, mg}/L\text{/hr} = \frac{(DO_1 - DO_2)}{(\text{Time}_1 - \text{Time}_2)} \times \frac{60 \text{ min}}{\text{hr}}$$
$$= \frac{(4.2 \text{ mg}/L - 1.8 \text{ mg}/L)}{5 \text{ min} - 2 \text{ min}} \times \frac{60 \text{ min}}{\text{hr}}$$
$$= 48 \text{ mg}/L\text{/hr}$$

3.22M

Known		Unknown
Digester Volume, Gal	= 1,000,000 gal	Digestion Time, days
Inflow, gpd	= 91,000 gpd	VSS Loading, lbs/day/cu ft
Infl. Sludge		VSS Destruction, %
SS, %	= 5.1%	
VM, %	= 76%	
Effl. Sludge		
SS, %	= 3.7%	
VM, %	= 67%	

Calculate the digestion time in days.

$$\text{Digestion Time, days} = \frac{\text{Digester Volume, gal}}{\text{Inflow, gpd}}$$
$$= \frac{1{,}000{,}000 \text{ gal}}{91{,}000 \text{ gpd}}$$
$$= 11.0 \text{ days}$$

Calculate the digester volume in cubic feet.

$$\text{Volume, cu ft} = \frac{\text{Volume, gal}}{7.48 \text{ gal/cu ft}}$$
$$= \frac{1{,}000{,}000 \text{ gal}}{7.48 \text{ gal/cu ft}}$$
$$= 133{,}700 \text{ cu ft}$$

Determine the volatile suspended solids applied (entering) in lbs/day.

$$\text{VSS Applied, lbs/day} = \text{Inflow, gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%} \times \frac{\text{VM, \%}}{100\%}$$
$$= 91{,}000 \text{ gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{5.1\%}{100\%} \times \frac{76\%}{100\%}$$
$$= 29{,}400 \text{ lbs/day}$$

Calculate the VSS loading in pounds per day per cubic foot.

$$\text{VSS Loading, lbs/day/cu ft} = \frac{\text{VSS Applied, lbs/day}}{\text{Digester Volume, cu ft}}$$
$$= \frac{29{,}400 \text{ lbs/day}}{133{,}700 \text{ cu ft}}$$
$$= 0.22 \text{ lbs VSS/day/cu ft}$$

Determine the volatile suspended solids exiting in lbs/day.

$$\text{VSS Exiting, lbs/day} = \text{Inflow, gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{SS, \%}}{100\%} \times \frac{\text{VM, \%}}{100\%}$$
$$= 91{,}000 \text{ gpd} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{3.7\%}{100\%} \times \frac{67\%}{100\%}$$
$$= 18{,}800 \text{ lbs/day}$$

Calculate the VSS destruction as a percent.

$$\text{VSS Destruction, \%} = \frac{(\text{VSS Applied, lbs/day} - \text{VSS Exiting, lbs/day}) \times 100\%}{\text{VSS Applied, lbs/day}}$$
$$= \frac{(29{,}400 \text{ lbs/day} - 18{,}800 \text{ lbs/day}) \times 100\%}{29{,}400 \text{ lbs/day}}$$
$$= 36.0\%$$

Answers to questions on page 166.

3.22N Process inefficiencies can be detected by careful observation of the physical sludge and routine monitoring of the DO and O_2 uptake rates. Laboratory analyses of influent and effluent suspended solids (% solids) and volatile matter content (% volatile matter) also will reveal process inefficiencies.

3.22O Normally digester DO is 1.5 mg/*L*. A DO residual of 4.0 mg/*L* is measured. The operator should verify the DO and check the O_2 uptake rates. If the O_2 uptake rate is normal, the air rate should be lowered. If the O_2 uptake rate is low, the cause should be identified and corrected. Possible causes include low digester temperature, low digester pH, too high or too low a VSS loading, and digestion time too high or too low.

3.22P Foaming problems.

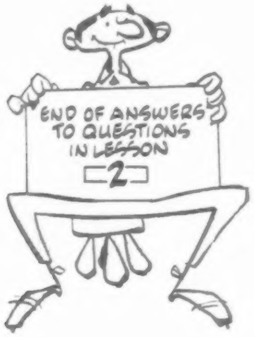
Potential Causes	Corrective Measures
1. Filamentous growth.	Increase air rate. Add defoamant.
2. Excessive turbulance.	Lower air rate. Add defoamant.

Answers to questions on page 167.

3.23A Two chemicals used to stabilize sludges are lime and chlorine.

3.23B Major limitations of using chemicals to stabilize sludge include (1) costs, and (2) the volume of sludge is not reduced.

3.23C Chemicals are used as a temporary stabilization process at overloaded plants or at plants experiencing stabilization facility upsets.


END OF ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 173.

3.30A Solid particles present in sludge usually require conditioning in order to separate from wastewater because they are fine in particle size, hydrated (combined with water) and may carry an electrostatic charge.

3.30B Different types of sludge conditioning methods include: (1) chemical treatment, (2) thermal treatment, and (3) elutriation. These are the most common. Other types include: freezing, electrical treatment and ultrasonic treatment.

3.31A The addition of chemicals to sludge reduces the natural repelling forces and allows the solids to come together (coagulate) and gather (flocculate) into a heavier solid mass.

3.31B Chemical types and dosage requirements vary from plant to plant because sludge types and characteristics vary from plant to plant.

3.31C Chemical requirements are determined for a particular sludge by the use of laboratory-scale "jar tests." Various amounts of a chemical are added to different jars containing the sludge. The chemical requirements are based on the volume of chemical solution required for floc formation.

3.31D

Known	Unknown
Polymer Added, lbs = 3 lbs	Strength of Solution, %
Total Volume, gal = 360 gallons	

Determine the strength of the polymer solution in percent.

$$\text{Solution, \%} = \frac{\text{Polymer Added, lbs} \times 100\%}{\text{Total Volume, gallons} \times 8.34\ \text{lbs/gal}}$$

$$= \frac{3\ \text{lbs} \times 100\%}{360\ \text{gallons} \times 8.34\ \text{lbs/gal}}$$

$$= 0.10\%$$

3.31E

Known	Unknown
Lime Added, lbs = 10 lbs	Strength of Solution, %
Total Volume, gal = 100 gallons	

Determine the strength of the lime solution in percent.

$$\text{Solution, \%} = \frac{\text{Chemical Added, lbs} \times 100\%}{\text{Total Volume, gallons} \times 8.34\ \text{lbs/gal}}$$

$$= \frac{10\ \text{lbs} \times 100\%}{100\ \text{gallons} \times 8.34\ \text{lbs/gal}}$$

$$= 1.20\%\ \text{lime}$$

3.31F

Known	Unknown
Liquid Polymer, gal = 10 gal	Strength of Solution, %
Volume Water, gal = 790 gal	

Determine the strength of the polymer solution in percent.

$$\text{Solution, \%} = \frac{\text{Polymer Added, gal} \times 100\%}{\text{Total Volume, gallons}}$$

$$= \frac{10\ \text{gal} \times 100\%}{(790\ \text{gal} + 10\ \text{gal})}$$

$$= 1.25\%$$

3.31G

Known	Unknown
Ferric Chloride, gal = 5 gal	Strength of Solution, %
Volume Water, gal = 50 gal	

Determine the strength of the ferric chloride solution in percent.

$$\text{Solution, \%} = \frac{\text{Ferric chloride, gal} \times 100\%}{\text{Total Volume, gallons}}$$

$$= \frac{5\ \text{gal} \times 100\%}{(50\ \text{gal} + 5\ \text{gal})}$$

$$= 9.1\%$$

3.31H

Known		Unknown
Sludge Conc.,		Polymer dose, lbs/ton
%	= 3.0%	Polymer cost, $/ton
mg/*L*	= 30,000 mg/*L*	
Polymer,		
Volume, ml	= 60 ml	
Strength, %	= 0.15%	
Cost, $/lb	= $1.50/lb	
Sludge Volume	= 1 liter = 0.265 gal	

Determine the dosage in pounds of polymer per ton of sludge.

$$\text{Dosage, lb/ton} = \frac{\text{Polymer Solution, \%} \times \text{Polymer Added, ml} \times 2}{\text{Sludge Volume, } L \times \text{Sludge Conc., \%}}$$

$$= \frac{0.15 \times 60 \times 2}{1 \times 3.0}$$

$$= 6\ \text{lbs dry polymer/ton of sludge}$$

Determine the cost in dollars of polymer per ton of sludge.

$$\text{Cost, \$/ton} = \text{Dosage, lb/ton} \times \text{Polymer Cost, \$/lb}$$

$$= \frac{\text{6 lbs Polymer}}{\text{ton of sludge}} \times \frac{\$1.50}{\text{lb Polymer}}$$

$$= \$9.00\text{/ton of sludge}$$

3.31I

Known		Unknown
Polymer Solution, %	= 2.5%	Dosage, lbs/ton
Polymer Flow Rate, GPM	= 3 GPM	Cost, $/ton
Sludge Flow, GPM	= 30 GPM	
Sludge Conc., %	= 4%	
Polymer Cost, $/lb	= $0.20/lb	

Determine the dosage of polymer in pounds of polymer per ton of sludge.

$$\text{Dosage, lbs/ton} = \frac{\text{Poly. Sol, \%} \times \text{Poly. Flow, GPM} \times \text{2000 lbs/ton}}{\text{Sludge Flow, GPM} \times \text{Sludge Conc., \%}}$$

$$= \frac{2.5\% \times \text{3.0 GPM} \times \text{2000 lbs/ton}}{\text{30 GPM} \times 4\%}$$

$$= \text{125 lbs/ton}$$

Determine the cost in dollars of polymer per ton of sludge.

$$\text{Cost, \$/ton} = \text{Dosage, lb/ton} \times \text{Polymer Cost, \$/lb}$$

$$= \text{125 lbs/ton} \times \$0.20\text{/lb}$$

$$= \$25\text{/ton of sludge}$$

Answers to questions on page 175.

3.31J Dry chemicals should be kept in a dry place to avoid chemical handling and transferring problems. If allowed to get wet, the dry chemicals will not move freely.

3.31K The purpose of wetting dry polymers is to produce a properly mixed solution that will not have balls of undissolved polymer.

3.31L Procedures to prepare a batch solution of dry chemicals.

1. Calculate amount of dry chemical needed.
2. Weigh out dry chemical.
3. Partially fill mix tank until impellers are submerged.
4. Turn on mixer.
5. Add product to mix tank.
6. Fill tank to desired level.
7. Allow to mix before use to sufficiently cure solution.
8. Turn off the mixer.

Procedures to prepare a batch solution of liquid chemicals.

1. Calculate the volume of liquid chemical needed.
2. Measure the volume of liquid chemical.
3. Follow steps 3 through 8.

3.31M Curing time is important to allow the chemical to fully dissolve and be as effective as possible.

3.31N Chemical tanks should be covered to prevent foreign material from entering and possibly clogging equipment. Polymers must be covered to protect polymers from ultraviolet sun rays.

3.31O Polymers should not be added to the suction side of sludge feed pumps because the shearing forces through such pumps tend to shear any floc formation.

3.31P If sludge thickening or dewatering inefficiencies cannot be traced back to equipment failures, check the chemical mixing (preparation) and addition equipment. With automatic feeding systems, the operator should check (1) the level of dry product in the storage hopper and replenish if necessary, (2) the screw conveyor and unplug if necessary, (3) the quality of the solution, and (4) the chemical addition pump.

Answers to questions on page 177.

3.32A When sludge particles are exposed to extreme heat at elevated pressures, the surrounding sheath hydrolyzes (decomposes) and ruptures the cell wall allowing bound water to escape.

3.32B The performance and efficiency of thermal conditioning systems are affected by: (1) the concentration and consistency of the influent sludge, (2) reactor detention times, and (3) reactor temperature and pressure.

3.32C

Known		Unknown
Reactor Volume, gal	=1,000 gal	Detention Time, min
Sludge Flow, GPM	=33 GPM	
Sludge Conc., %	=4.0%	

Calculate detention time in minutes.

$$\text{Detention Time, min} = \frac{\text{Reactor Volume, gal}}{\text{Flow, GPM}}$$

$$= \frac{\text{1,000 gal}}{\text{33 gal/min}}$$

$$= \text{30 min}$$

3.32D

Known	Unknown
Information from 22.32C	Reactor Detention Time, min
Sludge Concentration Decreases to 2.5%	

Estimate the reactor detention time in minutes.

$$\text{Detention Time, min} = \frac{\text{Old Detention Time, min} \times \text{New Conc., \%}}{\text{Old Sludge Conc., \%}}$$

$$= \text{30 min} \times \frac{2.5\%}{4.0\%}$$

$$= \text{19 min}$$

3.32E Operating controls available to optimize thermal conditioning facilities include: (1) inlet sludge flow, (2) reactor temperature and detention time, and (3) sludge withdrawal from the decant tank.

3.32F Gasification usually is not a problem in gravity thickeners with thermally treated sludge because of the lack of biological activity.

Answers to questions on page 178.

3.32G Continuous operation is desirable because energy is not wasted in allowing the heat exchanger and reactor contents to cool down and be heated back to the desired temperature each day when operated as a batch process.

3.32H Start-up procedures:

1. Fill reactor and heat exchangers with water if necessary.
2. Turn on boiler make-up water pump or open valve to the steam boiler.
3. Open required steam valves.
4. After desired temperature is reached, open inlet sludge and outlet valves.

5. Turn on sludge grinder and stirring mechanisms.
6. Turn on vent fan and activate odor control equipment.
7. Turn on sludge feed pump.

Reverse procedure for shutdown.

3.32I A log of the pressure drop across the heat exchangers must be kept so the operator can determine when the pressure drop is excessive. When the pressure drop becomes excessive, the system should be acid flushed to remove scale deposits and to unplug the heat exchangers.

3.32J Loss of sludge dewaterability.

Possible Causes	**Corrective Measures**
1. Low Temperature	1. Increase Temperature. Check fuel supply and system, instrumentation and make-up water supply.
2. Low or Short Detention Time	2. Thicken feed sludge.
3. Poor Operation of Decant	3. Thicken underflow sludge.

Answers to questions on page 180.

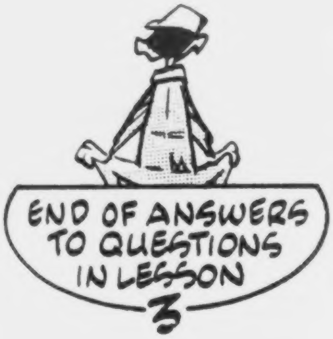
3.33A The major difference between LPO, IPO, and HPO is the pressures (low, 400 psig; intermediate, 500 to 600 psig; high, 1,000 to 1,500 psig) in the reactor. As the pressures increase, the amount of air reacted with the feed sludge and temperatures also increase.

3.33B The performance and efficiency of wet oxidation units are dependent on: (1) the concentration and consistency of the feed sludge, (2) reactor detention times, (3) reactor temperature and pressure, and (4) the quantity of air supplied.

3.33C Air pollution control equipment is required on thermal treatment units due to the production of noxious odors.

Answers to questions on page 181.

3.34A Elutriation improves the dewaterability of sludge by washing out the fine, difficult to dewater solids. Problems associated with the elutriation process result from solids lost to the plant effluent with the elutriation effluent (elutriate). The loss of these fine solids into the plant effluent will deteriorate the effluent quality while recycling to the plant headworks generally results in operational problems due to buildup of fine solids throughout the system.


END OF ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 185.

3.40A The primary objective of sludge dewatering is to reduce sludge moisture and consequently sludge volume to a degree that will allow for economical disposal.

3.40B Unit processes most often used for sludge dewatering are: (1) pressure filtration, (2) vacuum filtration, (3) centrifugation, and (4) sand drying beds.

3.41A Flow through plate and frame filter presses decreases with filtration time because as the cake builds up between the plates, the resistance to flow increases as the water passes through thicker and thicker layers of compacted solids.

3.41B Pressure filtration performance is affected by (1) sludge type, (2) conditioning, (3) filter pressure, (4) filtration time, (5) solids loadings, (6) filter cloth type, and (7) precoat.

3.41C Increasing the operating pressure might result in wetter cakes when dewatering secondary sludges. As the pressure is increased, the sludge retained on the filtering media may compress to a higher degree and reduce the porosity (openings) of the sludge cake that is formed. If the openings are reduced, fine low-density solids may be captured which result in wetter cakes because these solids have large surface areas and relatively large quantities of water associated with them.

3.41D The time of filtration depends on the physical size of the filter and applied solids loading rate. The operator controls filtration time on the basis of the actual filtrate flow rate. When the cavities between the plates are filled with solids and the filtrate flow is almost zero, the filtering sequence is complete.

3.41E The purpose of precoating is to reduce the frequency of media washing and to facilitate cake discharge.

3.41F Normal operating procedures for a filter press are as follows:

1. Slurry precoat mix.
2. Transfer slurry to tank containing sludge and gently stir. Add ferric chloride if used.
3. Apply the precoat material to the filter.
4. Introduce the conditioned sludge to the filter.
5. When the filtrate flow decreases to near zero, turn off the feed pump.
6. Disengage and open the press for cake discharge.
7. Close the press and repeat the above procedures.

3.41G Secondary sludges do not dewater as readily as primary sludges because secondary sludges contain fine, low-density solids that have large surface areas and relatively large quantities of water associated with them.

Answers to questions on page 186.

3.41H If discharge cakes from a filter press are wet throughout, try to identify the cause and correct the problem. Causes of wet cakes include: (1) low filtration time, (2) low pressure, and (3) chemical inefficiencies.

3.41I Solids may cling to filtering media when the cakes are discharged due to precoat inefficiencies.

Answers to questions on page 189.

3.41J The purpose of the drainage zone (portion of the belt) is to allow for most of the free water to drain through the filter and to be collected in a trough on the underside of the belt.

3.41K Mix chambers can be used to ensure adequate polymer and sludge contact.

3.41L Some belt filter presses use a reaction chamber instead of the horizontal drainage zone to allow most of the free water to drain out.

3.41M In the "press" or "dewatering zone" the entrapped solids are subjected to shear forces created as the two belts travel over rollers which bring them closer and closer together. Water is forced from between the belts and collected in filtrate trays while the retained solids are scraped from the two belts when they separate at the discharge end of the press.

3.41N The ability of belt filter presses to dewater sludge and to remove suspended solids is dependent on: (1) sludge type, (2) conditioning, (3) belt tension or pressure, (4) belt speed, (5) hydraulic loading, and (6) belt type.

3.41O When using a belt press to dewater secondary sludges, the sludges may tend to slip towards the belt sides and eventually squeeze out from between the belts. The net effects are that these solids contaminate the effluent by falling into the filtrate trays and continued housekeeping is required.

3.41P As the belt tension is increased, more water is generally squeezed from the belt which results in drier cakes.

3.41Q Low belt speed affects belt press performance because as the belt speed decreases, cake dryness increases because the sludge is subjected to pressure and shearing forces for longer periods of time.

3.41R Washing out means that large quantities of free water unable to be released in the drainage zone will travel to the dewatering zone and flow out from between the belts and drastically reduce effluent quality.

3.41S The ideal operating belt speed is the slowest the operator can maintain without "washing out" the belt.

3.41T Porosity of a belt depends on the belt type. As the porosity increases, the resistance to flow decreases and larger volumes of water are able to be drained. If the porosity is too low, the belt may blind or plug which will produce frequent "washouts."

Answers to questions on page 189.

3.41U If "washing out" of the belt develops, check: (1) polymer dosage, (2) hydraulic loading, (3) belt speed, and (4) washing equipment.

3.41V Blinding can be corrected by reducing the polymer dosage.

Answers to questions on page 195.

3.41W The purpose of the agitator in the trough is to keep the chemically conditioned sludge well mixed and to prevent the sludge from settling in the trough.

3.41X In the "mat formation" or "sludge pick-up zone," the vacuum is applied to the compartments of the drum submerged in the trough. This vacuum causes the sludge to be picked up on the filter media and a sludge mat is formed.

In the "drying zone" of the cycle, the drum rotates out of the trough. When this occurs, the vacuum is decreased slightly and water is sucked from the sludge mat, through the filter media and discharged through internal pipes to a drainage system.

3.41Y The filter media passes through a washing zone to remove fine particles and to reduce the possibility of media blinding.

3.41Z Factors affecting vacuum filtration performance include: (1) sludge type, (2) conditioning, (3) applied vacuum, (4) drum speed or cycle time, (5) depth of submergence, and (6) media type and condition.

3.41AA The operator should maintain a vacuum of 15 to 30 inches (38 to 75 cm) of mercury.

3.41AB The lower the cycle time the higher the degree of dewatering. Cycle time controls the rate of sludge pick-up and the thickness of the sludge mat in the "formation zone." Also cycle time controls the length of time the sludge remains in the "drying zone."

3.41AC

Known	**Unknown**
Vacuum Filter	Filter Yield, lbs/hr/sq ft

Surface Area, sq ft = 300 sq ft
Sludge Flow, GPM = 75 GPM
Suspended Solids, % = 4.7%
Filter Recovery, % = 95%

Calculate the filter yield in pounds per hour applied per square foot of filter surface area.

$$\text{Filter Yield, lbs/hr/sq ft} = \frac{\text{Flow, GPM} \times 8.34\text{ lbs/gal} \times 60\text{ min/hr} \times \text{Solids, \%} \times \text{Recovery \%}}{\text{Surface Area, sq ft} \times 100\% \times 100\%}$$

$$= \frac{75\text{ gal/min} \times 8.34\text{ lbs/gal} \times 60\text{ min/hr} \times 4.7\% \times 93\%}{300\text{ sq ft} \times 100\% \times 100\%}$$

$$= \frac{1640\text{ lbs/hr}}{300\text{ sq ft}}$$

$$= 5.5\text{ lbs/hr/sq ft}$$

3.41AD As the porosity (openings) of the media increases, the ability to capture suspended solids decreases because fine, low density solids can pass directly through the media. If the porosity of the media decreases too much, the media can blind with fine solids or chemical coatings, sludge will not be picked up in the formation zone and the vacuum filter will be rendered inoperative.

Answers to questions on page 196.

3.41AE A loss of vacuum can be caused by: (1) filter media misaligned, (2) tear in filter media. (3) trough empty and (4) vacuum pumps inoperative. A loss of vacuum will result in deteriorations of effluent quality and wet cakes that are difficult to discharge from the belt.

3.41AF If sludge is not picked up in the formation zone, a poor effluent quality will result. To look for the cause of poor effluent quality, look for (1) a loss of vacuum, or (2) insufficient chemical conditioning.

3.41AG To increase cake dryness, the operator could: (1) increase vacuum, (2) reduce drum speed, and (3 improve chemical conditioning.

Answers to questions on pages 196 and 197.

3.42A Higher scroll speeds are usually required to dewater sludges as compared to sludge thickening because the concentration of feed sludge is somewhat higher for dewatering than for thickening.

3.42B

Known		Unknown
Sludge Flow, GPM	= 60 GPM	Hydraulic Loading, gal/hr
Sludge Solids, %	= 3.0%	Solids Loading, lbs solids/hr
Polymer Solution, %	= 2.5%	Polymer Dose, lb polymer/ton sludge
Polymer Flow, GPM	= 2 GPM	

Determine the hydraulic loading in gallons per hour.

$$\begin{aligned}\text{Hydraulic Loading, gallons/hr} &= \text{Flow, GPM} \times 60 \text{ min/hr}\\ &= 60 \text{ gal/min} \times 60 \text{ min/hr}\\ &= 3{,}600 \text{ gal/hr}\end{aligned}$$

Calculate the solids loading in pounds per hour.

$$\begin{aligned}\text{Solids Loading, pounds/hr} &= \text{Flow, GPM} \times 8.34 \text{ lbs/gal} \times 60 \text{ min/hr} \times \frac{\text{Solids, \%}}{100\%}\\ &= 60 \text{ gal/min} \times 8.34 \text{ lbs/gal} \times 60 \text{ min/hr} \times \frac{3.0\%}{100\%}\\ &= 900 \text{ pounds solids/hr}\end{aligned}$$

Determine the polymer flow in pounds per hour.

$$\begin{aligned}\text{Polymer Flow, lbs/hr} &= \text{Flow, GPM} \times 8.34 \text{ lbs/gal} \times 60 \text{ min/hr} \times \frac{\text{Polymer, \%}}{100\%}\\ &= 2 \text{ gal/min} \times 8.34 \text{ lbs/gal} \times 60 \text{ min/hr} \times \frac{2.5\%}{100\%}\\ &= 25 \text{ pounds polymer/hr}\end{aligned}$$

Calculate the polymer dose in pounds of polymer applied per ton of sludge treated.

$$\begin{aligned}\frac{\text{Polymer Dose, lbs/polymer}}{\text{ton sludge}} &= \frac{\text{Polymer Flow, lbs/hr} \times 2000 \text{ lbs/ton}}{\text{Solids Loading, lbs/hr}}\\ &= \frac{25 \text{ lbs polymer/hr} \times 2000 \text{ lbs/ton}}{900 \text{ pounds solids/hr}}\\ &= 55.6 \text{ pounds polymer per ton sludge}\end{aligned}$$

3.42C

Known		Unknown
48-in. diam. basket centrifuge		Is feed time ok?
Sludge Flow, GPM	= 50 GPM	
Sludge Feed, %	= 2.7% Solids	
Solids Recovery, %	= 95%	
Stored Solids, %	= 23%	
Feed Time, min	= 17 min	
Basket Capacity, cu ft	= 16 cu ft	

Determine the volume available to store solids in pounds.

$$\begin{aligned}\text{Solids Stored, lbs} &= \text{Volume, cu ft} \times \frac{7.48 \text{ gal}}{\text{cu ft}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{\text{Solids, \%}}{100\%}\\ &= 16 \text{ cu ft} \times \frac{7.48 \text{ gal}}{\text{cu ft}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{23\%}{100\%}\\ &= 230 \text{ lbs solids}\end{aligned}$$

Determine solids retained in pounds per minute.

$$\begin{aligned}\text{Solids Retained, lbs/min} &= \text{Flow, GPM} \times 8.34 \text{ lbs/gal} \times \frac{\text{Solids, \%}}{100\%} \times \frac{\text{Recovery, \%}}{100\%}\\ &= 50 \frac{\text{gal}}{\text{min}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{2.7\%}{100\%} \times \frac{95\%}{100\%}\\ &= 10.7 \text{ lbs solids/min}\end{aligned}$$

Calculate feed time in minutes.

$$\begin{aligned}\text{Feed Time, min} &= \frac{\text{Solids Stored, lbs}}{\text{Solids Retained, lbs/min}}\\ &= \frac{230 \text{ lbs solids}}{10.7 \text{ lbs solids/min}}\\ &= 21.5 \text{ min}\end{aligned}$$

The feed time should be increased from 17 to 21 minutes.

3.42D If the centrate quality is poor, but discharge solids are dry:

Possible Causes	Possible Solutions
1. Feed time too long.	1. Lower feed time.
2. Flow rate too high.	2. Lower flow rate.
3. Chemical inefficient.	3. Increase chemical dosage.

Answers to questions on page 199.

3.43A Sludge drying beds are usually not used for sludges that have been stabilized via wet oxidation because of the odorous nature of thermally heated sludge.

3.43B Factors affecting sand drying bed performance include: (1) sludge type, (2) conditioning, (3) climatic conditions, (4) sludge application rates and depths, and (5) dewatered sludge removal techniques.

3.43C Care must be taken to prevent chemical overdosing for two reasons: (1) media blinding with unattached polymer may develop, and (2) large floc particles that settle too rapidly may also blind the media.

3.43D Primary sludge from the bottom of a digester may require prescreening because greases, hair-like and stringy material can clog the sand bed.

3.43E Drying beds are usually covered in wet or cold climates to protect the drying sludge from rain and to reduce the drying period during cold weather. Covered drying beds should be well ventilated to promote evaporation and the cover serves to control odors and insects.

3.43F

Known		Unknown
Sand Drying Bed		Application Depth, in
Length, ft	= 150 ft	
Width, ft	= 30 ft	
Loading, lbs/yr/sq ft	= 15 lbs/yr/sq ft	
Applications, no./mo.	= 1 per month	
Sludge solids, %	= 3.0%	

Determine the total pounds of sludge that can be applied during the year.

$$\begin{aligned}\text{Sludge Applied, lbs/yr} &= \text{Loading, lbs/yr/sq ft} \times \text{Length, ft} \times \text{Width, ft}\\ &= 15 \text{ lbs/yr/sq ft} \times 150 \text{ ft} \times 30 \text{ ft}\\ &= 67{,}500 \text{ lbs/yr}\end{aligned}$$

NOTE: Standby area not included in this calculation.

Calculate the total volume of sludge applied in gallons per year.

$$\text{Sludge Applied, gallons/yr} = \frac{\text{Sludge Applied, lbs/yr}}{8.34 \text{ lbs/gal} \times \text{Sludge Solids, \%/100\%}}$$

$$= \frac{67{,}500 \text{ lbs/yr}}{8.34 \text{ lbs/gal} \times 3.0\%/100\%}$$

$$= 269{,}784 \text{ gal/yr}$$

Calculate the depth of sludge in inches per application.

$$\text{Sludge Depth, in/applic.} = \frac{\text{Sludge Applied, gal/yr} \times 12 \text{ in/ft}}{7.48 \text{ gal/cu ft} \times \text{Length, ft} \times \text{Width, ft} \times \text{Appl/yr}}$$

$$= \frac{269{,}784 \text{ gal/yr} \times 12 \text{ in/ft}}{7.48 \text{ gal/cu ft} \times 150 \text{ ft} \times 30 \text{ ft} \times 12 \text{ appl/yr}}$$

$$= 8 \text{ in/application}$$

3.43G To determine the optimum depth of sludge to be applied to sand beds, the operator should apply different depths of sludge to different sand beds, allow the sludge to dry and be removed, and then calculate the loading rate in pounds of sludge per year per square foot of drying bed area. The highest loading rate indicates the optimum depth of sludge.

3.43H Sand bed compaction should be avoided to prevent reduced drainage rates, longer drying times, and an increased potential for plugging.

3.43I The sand bed surface should be raked after sludge is removed to break up any scum or mat formations.

3.43J The final concentration to which the sludge can be dried is dependent on the climatic conditions and time the sludge remains in the bed after the majority of water has drained through the sand.

3.43K The only problem that appears to develop at most sludge drying bed installations is plugging of the media surface.

Answers to questions on page 202.

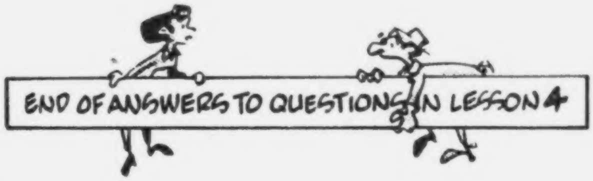
3.44A One limitation of using sand drying beds is that the dried sludge must be removed manually with forks or shovels.

3.44B To fill a surfaced drying bed that has gravel only in the drainage trench, start by adding water until the gravel is flooded. Digested sludge may be applied to the drying bed after the gravel is flooded.

3.44C When water-sludge separation is observed in a beaker containing digested sludge, partially open the drying bed drain line valve to drain off the water from the drying bed.

Answers to questions on page 203.

3.45A A successful sludge dewatering program requires that: (1) the operator be very familiar with the operation of the particular dewatering device(s) used, (2) sludge conditioning be optimum, and (3) the influent sludge be as thick and consistent as possible.


END OF ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 208.

3.50A The distinction between drying and incineration is that *DRYING* removes water from sludge *WITHOUT* the *COMBUSTION* of solid material while *INCINERATION* results in *COMBUSTION OR BURNING* of solid material. Composting is a drying process which removes moisture without the combustion of solid material.

3.51A A suitable environment must be established in compost piles for the thermophilic facultative aerobic microorganisms.

3.51B Chemically stabilized or wet-oxidized sludges are generally not suited for compost operations. Chemical stabilization produces environments that are unsuitable for microorganism survival and will not support life of composting bacteria unless the sludges are neutralized and favorable conditions exist. Sludge that has been stabilized by wet oxidation can be composted, but noxious thermal odors are likely to occur in and around the compost operation.

3.51C Criteria necessary to create a suitable compost environment include:

1. Sludges must be blended with previously composted material or bulking agents such as sawdust, straw, wood shavings, rice hulls, or leaves.
2. Aeration must be sufficient to maintain aerobic conditions in the composting material.
3. Proper moisture content and temperatures must be maintained.

3.51D Factors affecting composting include: (1) sludge type, (2) initial moisture content and homogeneity of the mixture, (3) frequency of aeration or windrow turning, (4) climatic conditions, and (5) desired moisture content of the final product.

3.51E Secondary sludges are not as easy to compost as primary sludges because of the plastic nature of dewatered secondary sludge and its higher moisture content. Dewatered secondary sludges tend to clump together and form "balls" when they are blended with compost material. The "balls" that are formed within the windrows readily dry on the outer surface but remain moist on the inside. The net effect of this "balling" phenomenon is the occasional creation of anaerobic conditions with odor production and a reduction in composting temperature.

3.51F

Known		Unknown
Dewatered Primary Sludge Solids, %	= 27%	Compost, lbs/day (need to produce 60% initial moisture content of mixture)
Dewatered Primary Sludge Solids, lbs/day	= 4700 lbs/day	
Dewatered Secondary Sludge Solids, %	= 15%	
Dewatered Secondary Sludge Solids, lbs/day	= 3300 lbs/day	
Combined Sludge Moisture, %	= 60%	
Compost Moisture Product, %	= 30%	

Determine the moisture content of the dewatered primary and secondary sludges in percent.

$$\text{Primary Sludge Moisture, \%} = 100\% - \text{Primary Sludge Solids, \%}$$

$$= 100\% - 27\%$$

$$= 73\%$$

$$\text{Secondary Sludge Moisture, \%} = 100\% - \text{Secondary Sludge Solids, \%}$$
$$= 100\% - 15\%$$
$$= 85\%$$

Determine the moisture content of the dewatered primary and secondary sludges in percent.

$$\text{Primary Sludge Moisture, \%} = 100\% - \text{Primary Sludge Solids, \%}$$
$$= 100\% - 27\%$$
$$= 73\%$$

$$\text{Secondary Sludge Moisture, \%} = 100\% - \text{Secondary Sludge Solids, \%}$$
$$= 100\% - 15\%$$
$$= 85\%$$

Determine the pounds per day of compost products that must be recycled and blended.

$$\text{Mixture Moisture, \%} = \frac{\text{Primary, lbs/day} \times \text{Pri. Moist, \%} + \text{Sec, lbs/day} \times}{\text{Primary, lbs/day} +}$$
$$\frac{\text{Sec. Moist. \%} + \text{Compost, lbs/day,} \times \text{Mix Moist, \%}}{\text{Sec, lbs/day} + \text{Compost, lbs/day}}$$

$$60\% = \frac{4700 \text{ lbs/day} \times 73\% + 3300 \text{ lbs/day} \times}{4700 \text{ lbs/day} + 3300 \text{ lbs/day} +}$$
$$\frac{85\% + \text{Compost, lbs/day} \times 30\%}{\text{Compost, lbs/day}}$$

Divide both sides by 100%:

$$0.60 = \frac{3431 + 2805 + 0.30 \text{ Compost, lbs/day}}{8000 + \text{Compost, lbs/day}}$$

$$0.60\,(8000 + \text{Compost, lbs/day}) = 3431 + 2805 + 0.30 \text{ Compost, lbs/day}$$

$$4800 + 0.60 \text{ Compost, lbs/day} = 6236 + 0.30 \text{ Compost, lbs/day}$$

Subtract 0.30 Compost, lbs/day and 4800 from both sides of equation.

$$0.30 \text{ Compost, lbs/day} = 1436$$

$$\text{Compost, lbs/day} = 4787 \text{ lbs/day}$$

3.51G Operational procedures for windrow composting.

1. Dewater sludge to highest degree practical.
2. Blend dewatered sludge with recycled compost or bulking agents to a consistency that will stack.
3. Form the windrow piles and turn (aerate) once or twice daily for the first 4 to 5 days after windrow formation.
4. Turn the piles approximately once every two days to once a week until the process is complete.
5. Load the compost onto trucks for disposal and recycle purposes.

3.51H The higher ratio of blend material and the longer compost times for secondary sludge develop because dewatered secondary sludges are wetter than dewatered primary sludges and it is more difficult to produce a homogeneous blend when secondary sludges are composted.

Answers to questions on page 210.

3.52A Indirect dryers use indirect contact of sludge with preheated gases by circulating steam through a jacketed hollow in an outer shell of a rotating cylindrical compartment. Direct driers use the direct contact of sludge with preheated gases.

3.52B The multiple-hearth furnace (MHF) is a direct drier because the hot gases come in contact with the sludge on the hearths.

3.52C Flights on rotary driers elevate and mix the sludge being dried to provide frequent contact of all wetted particles with hot gas streams or heated surfaces for direct or indirect drying, respectively.

3.52D Blending of the sludge with the dried product is generally practiced to improve the conveying characteristics of the sludge and to reduce the potential for balling and bridging.

3.52E Sludge should be dewatered to the highest degree practical to reduce the volume of water delivered to the drier and to facilitate the drying process.

3.52F As the drum speed increases, the drying time decreases because the sludge is picked up and tumbled towards the outlet at a faster rate. To increase the drying time the operator should lower the drum speed and/or reduce the quantity of sludge applied, if possible.

Answers to questions on page 217.

3.53A Sludge incineration is the conversion of dewatered sludge cake by combustion to ash, carbon dioxide, and water vapor.

3.53B The refractory is a term for bricks resistant to high temperatures.

3.53C On the center shaft there are arms to which plows are attached. These arms are called rabble arms and the plows are called rabble teeth.

3.53D The purpose of the lute cap is to prevent air and sludge from passing through the shaft opening, rather than the drop holes.

3.53E The purpose of the sand seal is to prevent the escape of heat and gases from the furnace and the entrance of air.

Answers to questions on page 223.

3.53F Furnace off-gas system.

Part	Purpose
1. Emergency by-pass damper	Vent gases to the atmosphere during emergency conditions. This device protects equipment and operating personnel.
2. Cyclone separator	Cause fly ash and heavy particles to settle out into the cyclone bin.
3. Precooler	Cool the furnace exhaust gases to saturation temperature and to wet the small particles of light ash.
4. Venturi scrubber	Clean the particulate matter from the cooled furnace gases.
5. Impingement scrubber	Trap remaining particles in flowing water.
6. Induced draft fan	Pull gases through the off-gas system and vent gases.
7. Induced draft damper	Regulate suction or draft within the MHF.
8. Ash handling system	Remove ash for ultimate disposal.

3.53G Burners are provided to supply the necessary heat to ignite the sludge.

3.53H The three ingredients necessary for combustion to occur are fuel, air, and temperature.

Answers to questions on page 228.

3.53I The three distinct zones in a furnace are the drying, combustion, and cooling zones.

3.53J The factors that influence the amount of fuel required include:

1. Conditions in the furnace,
2. Moisture content of the sludge,
3. Volatile content of the solids, and
4. Feed rate of the cake.

3.53K Combustion is a chemical reaction which requires oxygen, fuel, and heat. In the furnace, air provides oxygen, the primary fuel is sludge, and heat comes from the burning sludge.

3.53L Shaft speed adjustment may be required for changes in cake feed rate, moisture content of sludge cake, heating value of dry solids, increase or decrease of temperatures by burners, the number of burners operating and the amount of excess air allowed into the furnace.

3.53M A burnout occurs when the sludge feed has been stopped and the fire continues to burn.

Answers to questions on page 230.

3.53N To bring a cold furnace up to temperature:

1. Slowly increase the temperature until the temperature is up to 200°F (93°C) throughout the furnace.
2. Hold the temperature at 200°F (93°C) until the refractory is dry and warm.
3. Increase the temperature at a rate of 50°F/hr (28°C/hr) until the temperature on a given hearth reaches 1000°F (540°C).
4. Once the temperature of a hearth reaches 1000°F (540°C), the temperature of the hearth may be increased at a rate of 100°F/hr (56°C/hr) until the burning zone of the furnace reaches 1600°F (870°C). At this point the feed to the furnace may be started.

3.53O An autogenous burn occurs when the volatile content of the sludge cake is high enough that the cake will burn without the additional heat input from the burners.

3.53P MHFs should be operated on a continuous basis to extend refractory life. If operation is not continuous, the refractory expands and contracts, ash gets into the joints and when the MHF is reheated the bricks expand and the bricks can break.

3.53Q Smoke is caused by too low an oxygen content in the furnace. The solution to this problem is to add air at or below the fire.

3.53R When in the furnace area, wear protective clothing including heavy leather gloves, face shield, hard hat, long sleeve shirt, and long pants.

Answers to questions on page 230.

3.54A Three purposes of facultative sludge storage lagoons are to:

1. Reduce volume of sludge,
2. Store sludge, and
3. Stabilize sludge.

Answers to questions on page 230.

3.61A Two important restraints on the ultimate disposal of sludge include allowable emissions to the atmosphere from furnaces and the health aspects of sludge applied to land involved in the food chain.

3.61B Sludge should not be applied on food crops because of the potential problems from toxic substances, viruses and pathogens.

Answers to questions on page 237.

3.62A Mechanically dewatered sludge may be disposed of by:

1. Sanitary landfill disposal,
2. On-site dedicated land disposal,
3. Agricultural reclamation, and
4. Composting and utilization.

3.62B The following types of surface runoff control facilities must be provided at an on-site dedicated land disposal operation:

1. Flood protection. The disposal site should be protected from flooding by a continuous dike.
2. Existing drainage. The existing drainage into the disposal site should be intercepted and directed outside the flood-protection dike.
3. Contaminated runoff. Runoff from the disposal site should be collected in a detention basin and allowed to evaporate during the summer or recycled to the treatment plant headworks.

Answers to questions on page 243.

3.62C Liquid digested sludge can be disposed of by:

1. High-rate incorporation into the surface soils of a site dedicated to land disposal (DLD),
2. Low-rate application to agricultural sites, and
3. Confinement in permanent lagoons.

3.62D Liquid sludge can be spread over land by:

1. Ridge and furrow,
2. Flooding, and
3. Subsurface injection.

3.62E Composted material can be disposed of by:

1. Providing a bagged commercial product for sale to the public as a soil amendment,
2. Providing compost for agricultural land use, and
3. Providing compost for nonagricultural land uses.

3.63F The surface layer of liquid on permanent lagoons must be aerobic to minimize nuisance odors and vector problems.

Answers to questions on pages 244 and 245.

3.63A An odor-monitoring program should monitor:

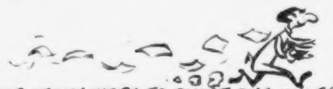
1. Meteorological conditions (air temperature at 5 and 25 feet above the ground, wind direction, and wind speed), and
2. Number of complaints.

3.63B There should be at least four test wells for a DLD site. Two of these should not extend below the confining soil layer and two should extend below this level.

Answers to questions on page 245.

3.7A Important items to consider when reviewing plans and specifications include:

1. Space for operation and maintenance of valves and pumps,
2. Meters and gages easily readable and located for ease in process adjustment if necessary,
3. Sufficient area, wash water capacity and drains to maintain, repair, and clean up equipment and areas, and
4. Provision for handling sludge when equipment fails.



END OF ANSWERS TO QUESTIONS IN LESSON 5

OBJECTIVE TEST

Chapter 3. SLUDGE HANDLING AND DISPOSAL

Please mark correct answers on the answer sheet as directed at the end of Chapter 1, Volume I, *OPERATION OF WASTEWATER TREATMENT PLANTS*. Return the answer sheet to your Program Director.

1. The flow to the primary and secondary treatment systems is the same as the plant influent flow.
   1. True
   2. False
2. Primary and secondary sludges are produced the same way.
   1. True
   2. False
3. The size of sludge handling equipment depends on the amount of water in the sludge mass.
   1. True
   2. False
4. The operator has no control over the depth of the sludge blanket in gravity thickeners.
   1. True
   2. False
5. Primary sludges are generally easier to treat than excess biological sludges in dissolved air flotation thickeners.
   1. True
   2. False
6. Dissolved air flotation thickeners that treat primary sludges should be equipped with bottom sludge scrapers and sludge removal equipment.
   1. True
   2. False
7. Centrifuges are commonly used to thicken primary sludges because the sludge inlet assemblies do not have problems with clogging.
   1. True
   2. False
8. Stabilized organic material usually gives off obnoxious odors.
   1. True
   2. False
9. The aerobic digestion process developed from the anaerobic digestion process.
   1. True
   2. False
10. Lime stabilization results in a greater volume or mass of sludge.
    1. True
    2. False
11. Chlorine stabilization can create a corrosive condition.
    1. True
    2. False
12. Jar tests should be followed by on-site tests for more accurate results.
    1. True
    2. False
13. Solution strengths of liquid polymers are based on the ratio of polymer weight to the weight of water.
    1. True
    2. False
14. Dry chemicals are usually mixed with water before application as a sludge conditioner. Drums or bulk storage tanks of dry chemicals should not be allowed to absorb moisture.
    1. True
    2. False
15. Polymers may be added to the suction side of sludge feed pumps without worrying about forces shearing any floc formation.
    1. True
    2. False
16. The high temperatures maintained in thermal reactors will sterilize the sludge and biological activity leading to gas production (gasification) is not likely to occur in the decant tanks.
    1. True
    2. False
17. Operation of the decant tank in a thermal conditioning system should follow the same procedures as for gravity thickeners.
    1. True
    2. False
18. The major difference between thermal conditioning and wet oxidation is that air is introduced for wet oxidation.
    1. True
    2. False

19. Secondary sludges dewater more readily and require less chemical conditioners than primary sludges when dewatered by filter presses.
    1. True
    2. False

20. A firm and dry cake indicates good filter press operation and no adjustments are necessary.
    1. True
    2. False

21. When operating a vacuum filter, attempt to maintain as high a vacuum as possible to obtain high degrees of dewatering.
    1. True
    2. False

22. Volume reduction processes should result in a complete destruction of pathogenic organisms in the sludges due to the low temperatures.
    1. True
    2. False

23. The plastic nature of dewatered secondary sludge and increased moisture content make secondary sludges easier to compost than primary sludges.
    1. True
    2. False

24. For complete combustion to occur in a multiple-hearth furnace, there must be a specific ratio between the amount of fuel and the amount of air.
    1. True
    2. False

25. The higher the volatile content of the solids in the sludge feed, the higher the fuel requirements.
    1. True
    2. False

26. In the multiple-hearth furnace, an excess amount of air must be available at all times.
    1. True
    2. False

27. If the burning zone in an MHF is too high, maintain the steady cake feed rate but *INCREASE* the speed of the central shaft (if possible).
    1. True
    2. False

28. Disposal of sludge cake by trenching operations in a dedicated land disposal site is not difficult during extreme wet periods.
    1. True
    2. False

29. Incinerated ash from grit, scum and screenings can be disposed of on a DLD site as long as it is turned under the soil quickly and not subject to wind action.
    1. True
    2. False

30. Successful operation of gravity thickeners depends on
    1. Control of sludge organisms.
    2. Proper application of the forces of gravity.
    3. Sludge blanket depth.
    4. Solids and hydraulic detention times.
    5. Solids and hydraulic loadings.

31. Possible causes of gasification in a gravity sludge thickener include
    1. Air dissolving in the sludge.
    2. Gases sinking into the sludge blanket.
    3. Sludge held too long in the clarifiers.
    4. Sludge scrapers operating at too low a speed.
    5. Too long a detention time in the thickeners.

32. A gravity thickener has a clear effluent, but the thickened (underflow) sludge is thin (dilute). How can the thickened sludge concentration be increased?
    1. Decrease depth of sludge blanket.
    2. Decrease sludge pumping from the clarifier.
    3. Decrease sludge withdrawal rate.
    4. Decrease solids loading.
    5. Increase sludge withdrawal rate.

33. In dissolved air flotation thickeners, floated solids are kept out of the effluent by the use of ____________?
    1. Effluent baffles
    2. Hardware cloth screens
    3. Macroscreens
    4. Scum scrapers
    5. Water sprays

34. High suspended solids in the effluent of a dissolved air flotation thickener unit may be caused by improper
    1. A/S ratio.
    2. Chemical conditioning.
    3. Recycle rate.
    4. Float blanket thickness.
    5. Hydraulic loading.

35. Which is the most important water quality analysis of aerobic digester contents?
    1. Alkalinity
    2. pH
    3. Oxygen uptake rates
    4. Residual dissolved oxygen
    5. Temperature

36. What problems are created by excessive air rates in an aerobic digester?
    1. Filamentous organisms will grow
    2. Turbulence will be created which affects sludge settleability
    3. Odor problems will develop
    4. Foaming problems may develop
    5. Energy is wasted

37. Problems that could develop from the improper storage of dry polymers during the mixing of the polymer with water include
    1. Activated polymer microorganisms biodegrading the polymer molecule.
    2. Foreign material entering the storage tank and clogging equipment.
    3. Temperatures above 130°F (54°C) breaking down the polymer molecule.
    4. Temperatures below 0°F (−18°C) freezing the polymer into lumps.
    5. Ultraviolet sun rays deteriorating the polymer molecules.

38. Key operating guidelines that the operator can control on a day-to-day basis for a thermal conditioning system include
    1. Detention time.
    2. Inlet sludge flow.
    3. Reactor recirculation rates.
    4. Reactor temperature.
    5. Sludge withdrawal from decant tank.

39. The performance and efficiency of wet oxidation units are dependent on the
    1. Concentration and consistency of the feed sludge.
    2. Quantity of air supplied.
    3. Reactor detention time.
    4. Reactor pressure.
    5. Reactor temperature.

40. Unit processes most often used for sludge dewatering are
    1. Centrifugation.
    2. Pressure filtration.
    3. Sand drying beds.
    4. Vacuum filtration.
    5. Wet oxidation.

41. A belt filter press is processing secondary sludges. Some of the sludge is squeezing out from between the belts and contaminating the effluent by falling into the filtrate trays. How would you correct this problem?
    1. Blend primary sludge with the secondary sludge
    2. Build baffles around the belts
    3. Chlorinate the effluent
    4. Filter the effluent
    5. Move the filtrate trays

42. What could be the possible causes of "washing out" of the belt on a belt filter press?
    1. Belt blinding
    2. Belt speed too low
    3. Belt tension needs adjustment
    4. Hydraulic load too high
    5. Polymer dosage insufficient

43. In wet or cold climates, sand drying beds are usually covered with greenhouse-type enclosures to
    1. Control odors.
    2. Grow vegetables and flowers.
    3. Promote evaporation.
    4. Reduce the drying period.
    5. Treat "green" sludge.

44. Compaction of the sand in a sand drying bed will result in
    1. Increased potential for plugging.
    2. Longer drying times.
    3. Need for more sand to maintain the specified depth of sand.
    4. Reduced drainage rates.
    5. Use of front-end loaders to remove dried sludge.

45. Windrow composting may have which of the following operational problems?
    1. Aerobic conditions
    2. Anaerobic conditions
    3. Balling
    4. Bulking
    5. Low compost temperatures

46. Incineration designs include
    1. Composting.
    2. Fluidized-bed reactor.
    3. Multiple-hearth furnace.
    4. Rotary kiln.
    5. Wet oxidation.

47. Sludge cake is moved through a multiple-hearth furnace by a process called
    1. Blowing.
    2. Dozing.
    3. Pushing.
    4. Rabbling.
    5. Turning.

48. The measurement of the negative pressure or vacuum created by convection flow in an MHF is called the ____________.
    1. Draft
    2. Head
    3. Lift
    4. Piezometer
    5. Rabble

49. In order to minimize leachate formation in a landfill, generally no more than ____ gallons of water per cubic yard of refuse should be allowed.
    1. 0 to 10
    2. 10 to 25
    3. 25 to 40
    4. 40 to 65
    5. 65 to 95

50. Contaminated runoff from an on-site dedicated land disposal operation may be disposed of by
    1. Discharge to a nearby stream.
    2. Discharge to groundwater.
    3. Evaporation during the dry season.
    4. Irrigation.
    5. Recycle to plant headworks.

51. Freshly dewatered sludge must be mixed with either previously composted sludge or a bulking material to achieve 35 to 40 percent solids content at the start of composting to allow sufficient voids and air passages

    1. For the aerobic composting process to be sustained.
    2. For winds to prevent the compost from exceeding combustion temperatures.
    3. To prevent odors from causing nuisances.
    4. To prevent the windrows from flowing or settling.
    5. To provide for continued anaerobic decomposition of the sludge.

52 and 53

To prevent erosion, the maximum field slope should be held to (52) _____ percent and the drainage ditches on the sides of each DLD site should be designed so that the runoff velocity does not exceed (53) _____ feet per second.

52.		53.	
1.	0.1	1.	1
2.	0.2	2.	2
3.	0.3	3.	3
4.	0.4	4.	4
5.	0.5	5.	5

54. Five thousand gallons of sludge with a sludge solids concentration of 2 percent is thickened to a sludge solids concentration of 5 percent. What is the reduction in volume of sludge? *HINT:* How many gallons of water were removed by the thickening process?

    1. 834 gallons
    2. 1000 gallons
    3. 2000 gallons
    4. 3000 gallons
    5. 4000 gallons

55. An air rotameter and compressor provide for 12 cubic feet per minute (SCFM) of air to be injected into a pressurized retention tank. How many pounds of air applied to the unit per hour?

    1. 54 lbs/hr
    2. 90 lbs/hr
    3. 100 lbs/hr
    4. 720 lbs/hr
    5. 6000 lbs/hr

56. An aerobic digester has a volume of 100,000 gallons and treats a flow of 10,000 GPD of thickened secondary sludge. How long is the digestion time?

    1. 0.1 day or 2.4 hours
    2. 0.13 day or 3.2 hours
    3. 1 day
    4. 7.48 days
    5. 10 days

57. An aerobic digester with a volume of 100,000 gallons receives 10,000 GPD of thickened secondary sludge. The sludge is 3.0 percent sludge solids and 70 percent volatile matter. What is the volatile sludge solids loading?

    1. 0.10 lbs VSS/day/cu ft
    2. 0.13 lbs VSS/day/cu ft
    3. 0.18 lbs VSS/day/cu ft
    4. 0.20 lbs VSS/day/cu ft
    5. 1.0 lbs VSS/day/cu ft

The following information is provided to answer questions 58 and 59.

A waste activated sludge is pumped at 50 GPM with a sludge solids concentration of 2.0 percent sludge solids. Jar tests indicate that 48 pounds per day of dry polymer are necessary for successful gravity thickening. The dry polymer costs $2.50 per dry pound.

58. What is the polymer dosage in pounds of polymer per ton of dry sludge solids?

    1. 2
    2. 4
    3. 5.5
    4. 8
    5. 10

59. What is the unit cost in dollars of polymer per ton of dry sludge solids?

    1. 5
    2. 10
    3. 13.75
    4. 20
    5. 25

60. A vacuum filter treats 5,000 pounds of sludge per day. The surface area of the filter is 200 square feet, the filter operates 8 hours per day with 95 percent solids recovery. What is the filter yield?

    1. 2.88 lbs/hr/sq ft
    2. 3.00 lbs/hr/sq ft
    3. 3.12 lbs/hr/sq ft
    4. 3.25 lbs/hr/sq ft
    5. 3.38 lbs/hr/sq ft

END OF OBJECTIVE TEST

CHAPTER 4

SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

by

James L. Johnson

and

Ross Gudgel

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OBJECTIVES

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

After completion of Chapter 4, you should be able to do the following:

CHEMICALS

1. Describe the proper procedures for using chemicals to remove solids from your treatment plant's secondary effluent.
2. Operate and maintain chemical feed equipment.
3. Safely store and handle chemicals.
4. Review plans and specifications of chemical feed systems.
5. Start up and shut down a chemical feed system.
6. Select the most cost-effective chemicals and determine proper dosage.
7. Troubleshoot a chemical feed system.
8. Develop an operational strategy for a chemical feed system.

MICROSCREENS

1. Identify and describe the components of a microscreen unit.
2. Safely operate and maintain a microscreen.
3. Start up and shut down a microscreen unit.
4. Troubleshoot a microscreen treatment process.
5. Develop an operational strategy for a microscreen treatment process.
6. Review plans and specifications for microscreens.

FILTRATION

1. Identify and describe the components of gravity and pressure filters.
2. Safely operate and maintain filters.
3. Start up and shut down filters.
4. Troubleshoot a filtration system.
5. Develop operational strategies for gravity and pressure filtration systems.
6. Review plans and specifications for filter systems.

GLOSSARY

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

AGE TANK AGE TANK

A tank used to store a known concentration of chemical solution for feed to a chemical feeder. Also called a "day tank."

AIR BINDING AIR BINDING

The clogging of a filter, pipe or pump due to the presence of air released from water.

ANHYDROUS (an-HI-drous) ANHYDROUS

Very dry. No water or dampness is present.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reacter is filled, the water is treated, and the tank is emptied. The tank may then be filled and the process repeated.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining or filtering.

CONTINUOUS PROCESS CONTINUOUS PROCESS

A treatment process in which water is treated continuously in a tank or reactor. The water being treated continuously flows into the tank at one end, is treated as it flows through the tank, and flows out the opposite end as treated water.

DAY TANK DAY TANK

A tank used to store a known concentration of chemical solution for feed to a chemical feeder. Also called an "age tank."

ELECTROLYTE (ELECT-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

FILTER AID FILTER AID

A chemical (usually a polymer) added to water to help remove fine colloidal suspended solids.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles.

FLOW-EQUALIZATION SYSTEM FLOW-EQUALIZATION SYSTEM

A device or tank designed to hold back or store a portion of peak flows for release during low-flow periods.

JAR TEST JAR TEST

A laboratory procedure that simulates coagulation/flocculation with differing chemical doses. The purpose of the procedure is to *ESTIMATE* the minimum coagulant dose required to achieve certain water quality goals. Samples of water to be treated are placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of the solids is observed. The lowest dose of chemicals that provides satisfactory settling is the dose used to treat the water.

POLYELECTROLYTE (POLY-electro-light) POLYELECTROLYTE

A high-molecular-weight substance that is formed by either a natural or a synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."

POLYMER (POLY-mer) POLYMER

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."

SLAKE SLAKE

To become mixed with water so that a true chemical reaction takes place, such as in the slaking of lime.

TURBIDITY UNITS TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

WATER HAMMER WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

CHAPTER 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

(Lesson 1 of 4 Lessons)

4.0 NEED TO REMOVE SOLIDS FROM SECONDARY EFFLUENTS

As increasing demands are placed upon our nation's receiving waters, it has become necessary to set wastewater treatment plant discharge standards at a level that cannot be consistently met by conventional secondary wastewater treatment plants.

At some locations, National Pollutant Discharge Elimination System (NPDES) discharge requirements as stringent as those listed in Table 4.1 are being imposed. To comply with these requirements, the effluent from a standard secondary treatment plant or pond system must receive additional or tertiary treatment. Improving solids removal from the effluent of secondary wastewater treatment plants may be accomplished by chemical addition or by several filtration processes. In addition to removing solids, these treatment processes also remove particulates, BOD and coliforms. This chapter will review methods presently in use for upgrading solids removal from the effluent of secondary treatment plants. These tertiary treatment methods include the addition of chemicals, microscreens, and gravity and pressure filters. Figure 4.1 shows the location of these tertiary treatment processes in relation to other conventional processes.

TABLE 4.1 EXAMPLE OF STRICT NPDES REQUIREMENTS

Water Quality Indicator	7-day Average	30-day Average	No Sample to Exceed
Biochemical Oxygen Demand (BOD_5), mg/*L*	5	5	7.5
Suspended Solids, mg/*L*	5	5	7.5
Total Coliform, MPN/100 ml *MEDIAN*, not average	2.2	2.2	240
Chlorine Residual, mg/*L* *AFTER* dechlorination	0	0	0

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

4.0A What do the initials NPDES stand for?

4.0B Why do some locations have stringent discharge requirements?

4.0C How can solids be removed from secondary effluents?

4.1 SOLIDS REMOVAL FROM SECONDARY EFFLUENTS USING CHEMICALS

Chemical treatment is a three-step process consisting of 1) *COAGULATION*[1], 2) *FLOCCULATION*[2], and 3) liquid/solids separation. The three steps must occur in the proper sequence. During the coagulation phase the chemical(s) are added to the wastewater and rapidly mixed with the process flow. At this time certain chemical reactions occur quickly, resulting in the formation of very small particles usually called "pin point floc."

Flocculation follows coagulation and consists of gentle mixing of the wastewater. The purpose of the gentle or slow mixing is to produce larger, denser floc particles that will settle rapidly. The liquid/solids separation step follows flocculation and is almost always conventional gravity settling, although other processes such as dissolved air flotation are used occasionally.

A chemical treatment process can be added on to an existing primary or secondary treatment plant as a tertiary treatment process. Chemical treatment performed in this manner requires the construction of additional basins or tanks, which may significantly increase the capital cost of the treatment plant. However, chemical treatment can be practiced by adding chemicals at specific locations in existing primary or secondary treatment plants. This approach is often called chemical addition, and it eliminates the need for constructing additional clarifiers.

Regardless of the form of the chemical treatment process (tertiary or chemical addition), the most important process control guidelines are:

1. Providing enough energy to completely mix the chemicals with the wastewater,
2. Controlling the intensity of mixing during flocculation, and
3. Controlling the chemical(s) dose.

Chemical treatment can easily be added to existing secondary treatment processes as chemical addition, and it may be added on a permanent basis to remove solids from the secondary effluent (Fig. 4.2). Filters (Sections 4.3 and 4.4) often are installed after chemical treatment to produce a highly polished effluent. Also, chemicals may be added to reduce emergency problems such as those created by sludge bulking in the secondary clarifier, upstream equipment failure, accidental spills entering the plant, and seasonal overloads. Chemicals can effectively be used as a "band-aid" during problem situations with relative minor capital expense.

---

[1] *Coagulation (co-AGG-you-LAY-shun). The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining or filtering.*

[2] *Flocculation (FLOCK-you-LAY-shun). The gathering together of fine particles to form larger particles.*

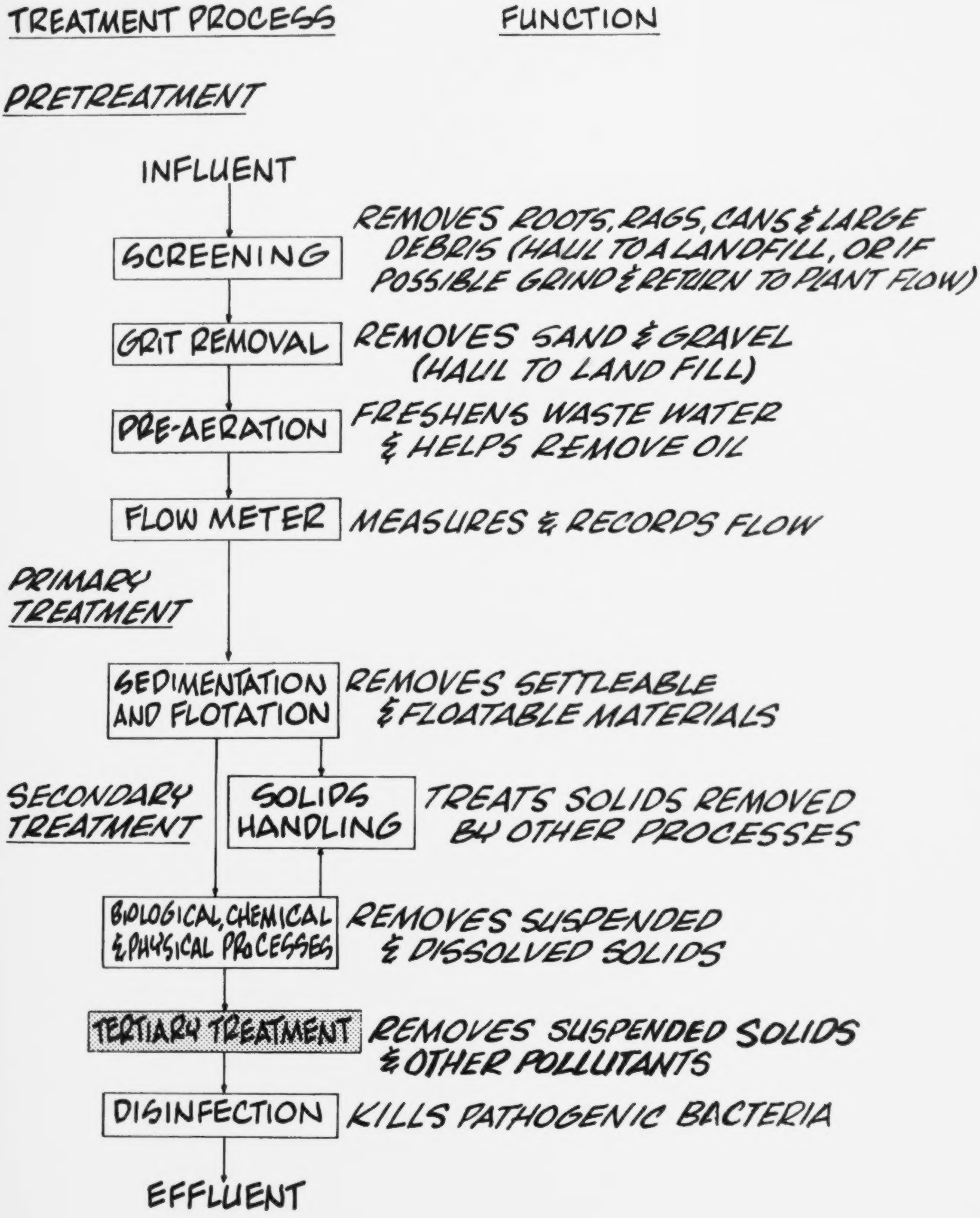

TREATMENT PROCESS
FUNCTION
PRETREATMENT
INFLUENT
SCREENING
REMOVES ROOTS, RAGS, CANS & LARGE DEBRIS (HAUL TO A LANDFILL, OR IF POSSIBLE GRIND & RETURN TO PLANT FLOW)
GRIT REMOVAL
REMOVES SAND & GRAVEL (HAUL TO LAND FILL)
PRE-AERATION
FRESHENS WASTE WATER & HELPS REMOVE OIL
FLOW METER
MEASURES & RECORDS FLOW
PRIMARY TREATMENT
SEDIMENTATION AND FLOTATION
REMOVES SETTLEABLE & FLOATABLE MATERIALS
SECONDARY TREATMENT
SOLIDS HANDLING
TREATS SOLIDS REMOVED BY OTHER PROCESSES
BIOLOGICAL, CHEMICAL & PHYSICAL PROCESSES
REMOVES SUSPENDED & DISSOLVED SOLIDS
TERTIARY TREATMENT
REMOVES SUSPENDED SOLIDS & OTHER POLLUTANTS
DISINFECTION
KILLS PATHOGENIC BACTERIA
EFFLUENT

Fig. 4.1 Flow diagram of a typical plant

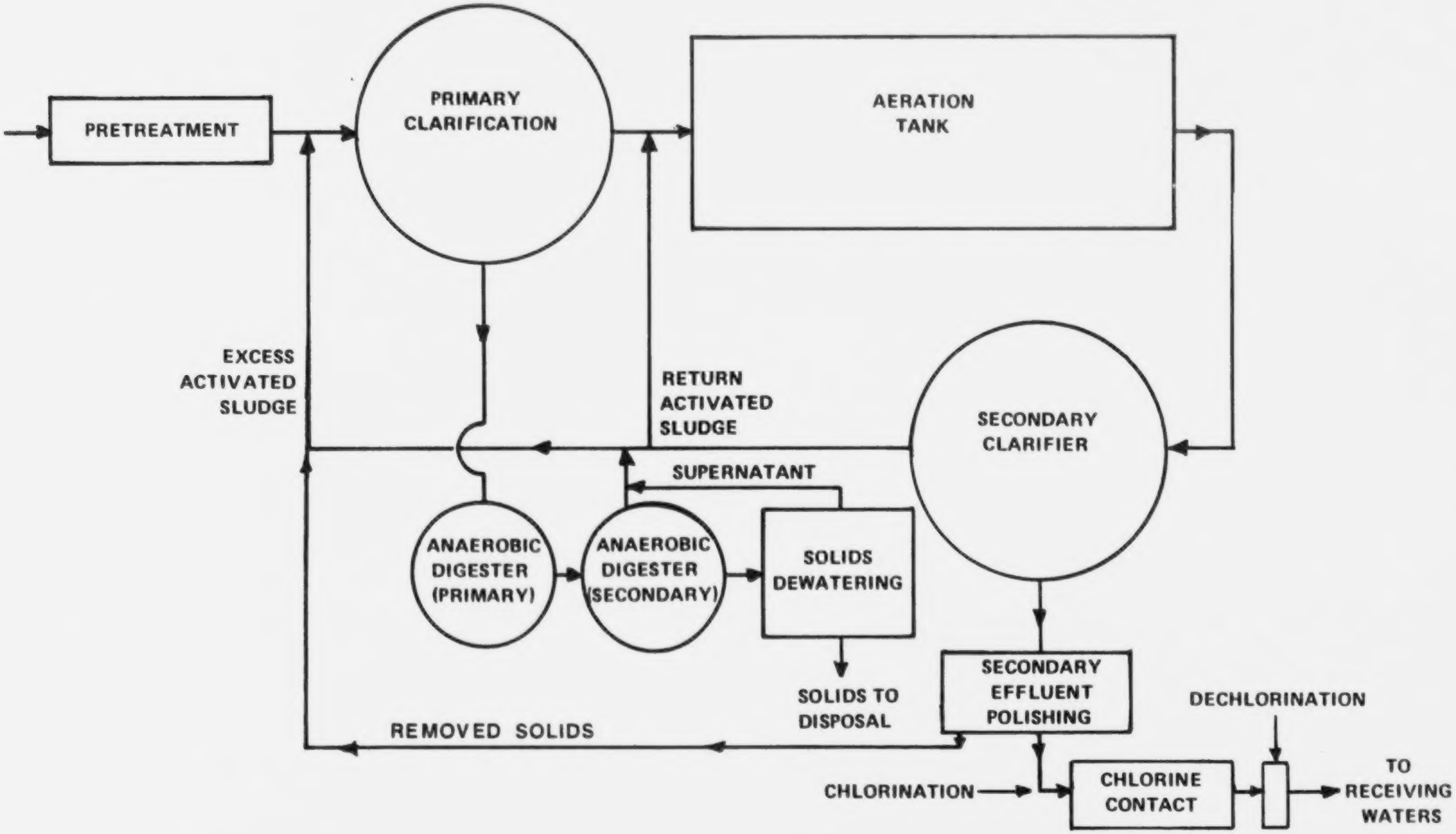

PRETREATMENT
PRIMARY CLARIFICATION
AERATION TANK
EXCESS ACTIVATED SLUDGE
RETURN ACTIVATED SLUDGE
SECONDARY CLARIFIER
SUPERNATANT
ANAEROBIC DIGESTER (PRIMARY)
ANAEROBIC DIGESTER (SECONDARY)
SOLIDS DEWATERING
SOLIDS TO DISPOSAL
SECONDARY EFFLUENT POLISHING
DECHLORINATION
REMOVED SOLIDS
CHLORINATION
CHLORINE CONTACT
TO RECEIVING WATERS

Fig. 4.2 Plan layout of a typical activated sludge plant with secondary effluent polishing process

Keep in mind that the addition of chemicals is usually meant to capture some additional solids; therefore, more sludge must be handled. Care must be taken in controlling dosage into the secondary system because large chemical additions may be toxic to the organisms. This will reduce the activity or even kill the organisms treating the wastes in the system.

Whenever applying chemicals it is important to always know, understand, and carefully control the dosage. You must understand each chemical's characteristics so the chemical will be properly stored and safely handled. *MANY OF THE CHEMICALS USED ARE HARMFUL, ESPECIALLY TO THE EYES. SAFETY IS OF THE UTMOST IMPORTANCE WHEN CHEMICALS ARE STORED OR APPLIED.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

4.1A Why might chemicals be used in a wastewater treatment plant in addition to removing solids from secondary effluents?

4.1B What precaution must be exercised when adding chemicals upstream from a biological treatment process?

4.10 Chemicals Added to Improve Settling

Secondary effluent quality may be improved by adding coagulant aids ahead of the secondary settling tanks. Chemicals usually added are alum, ferric chloride, lime or polyelectrolytes. Other useful chemicals may include sodium aluminate, ferric sulfate, ferrous chloride and ferrous sulfate. These chemicals may be used alone or in combinations as determined by laboratory testing (Section 4.12, "Determining Chemical Dosage") and the results obtained in actual plant operation.

4.100 Aluminum Sulfate (Dry) $(Al_2(SO_4)_3 \cdot 14\ H_2O)$

Alum may be purchased in varying grades identified as lump, ground, rice, and powdered. Lump alum consists of lumps varying in size from 0.8 inches to 8 inches (2 to 20 cm) in diameter and is rarely used due to its irregularity in size and the difficulties of applying and achieving a satisfactory dose. Ground (granulated) alum is a mixture of rice-size material and some fines (very small particles). This form of alum is used by the majority of the water and wastewater plants. Ground alum feeds easily and doesn't bulk (stick together) in the hoppers if kept free of moisture or water. Also, ground alum doesn't require special protection of the hopper interiors from corrosion and wear.

Commercial filter alum (ground alum) is shipped in 100-pound (45 kg) bags or in bulk trucks and railroad hopper cars. Special care should be taken to prevent alum from getting damp or it will cake into a solid lump. All mechanical equipment, such as conveyors, should be run until well-cleaned of all alum before shutting down because the alum can harden and jam the equipment. Keep alum dry by storing it inside a well-ventilated location. Storage bins should have a 60-degree slope to the bottom to insure complete emptying. Be sure the alum will not get wet when hosing down equipment or washing floors.

Both dry dust and liquid forms of alum are irritating to the skin and mucous membranes and can cause serious eye injury. Wear protective clothing to protect yourself from dust, splashes, or sprays. Proper clothing consists of a face shield, rubber gloves, rubber shoes and rubber clothing when working around alum dust.

4.101 Aluminum Sulfate (Liquid)

Alum is also available as a liquid. One gallon weighs about 11 pounds and contains the equivalent of 5.4 pounds of dry aluminum sulfate. Obtain a chemical analysis from the supplier for each delivery to determine the exact content. Liquid alum is preferred by operators because of its ease of handling; however, you must pay shipping costs for transporting the water portion.

Liquid alum is shipped in 2,000- to 4,000-gallon tank trucks or 55- to 110-ton railroad tank cars.

Alum becomes very corrosive when mixed with water; therefore, dissolving tanks, pumps and piping must be protected. Liquid storage tanks must be constructed of corrosion resistant material such as rubber-lined steel or fiberglass. Bulk liquid alum storage tanks must be protected from extreme cold because normal commercial concentrations will crystallize at temperatures below 32°F (0°C) and freeze at about 18°F (−8°C).

Alum will support a bacterial growth and/or cause sludge deposits in feed lines if wastewater is used to transport the alum to the point of application. These growths and deposits can completely plug the chemical feed line. This problem can be reduced by maintaining a high velocity to scour the line continuously. Also, a concentrated alum solution will not support the bacterial growth so reducing the amount of carrier water helps.

Alum reduces the alkalinity in the water being treated during the coagulation process. Hydrated lime, soda ash, or caustic soda may be required if there isn't enough natural alkalinity present to satisfy the alum dosage.

Overdosing of alum may depress the pH to a point that it will reduce the biological activity in the secondary system. Also, this lowered pH may allow the chlorine added as a disinfectant to further depress the pH and affect the aquatic life in the receiving waters. This, along with chemical costs, emphasizes the need to maintain proper chemical dosages and close monitoring of effluent quality.

Regularly analyze the bulk chemicals to determine if the concentration has changed. If the concentration has changed, the operator must adjust the chemical feed rate. Also test the effluent quality to determine if sufficient solids are being removed or if an adjustment in the chemical feed rate might be helpful.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 331.

4.1C What are the four most common chemicals added to improve settling of solids?

4.1D Why should alum be kept dry?

4.1E Why should all mechanical equipment, such as conveyors, be run until well-cleaned of all alum before shutting down?

4.102 Ferric Chloride

Ferric chloride is available in three forms — *ANHYDROUS*[3], crystal hydrated and liquid. The dry forms will absorb enough moisture from the air to quickly form highly corrosive solutions.

Anhydrous ferric chloride is shipped in 150- and 350-pound drums. Once these drums are opened, they should be completely emptied to prevent the formation of corrosive solutions. Care must be taken when making up solutions because the temperature of the solution will rise as the chemical dissolves.

Crystal ferric chloride is shipped in 100-, 400-, or 450-pound drums. Store the crystals in a cool, dry place and always completely empty any opened containers. The heat rise in dissolving crystal ferric chloride is much lower than that of anhydrous ferric chloride and is not a problem.

Liquid ferric chloride is shipped in rubber-linked tank cars or trucks and must be stored in corrosion-resistant tanks.

Positive displacement metering pumps should be used for accurate measurements. Both the feeder and the lines must be corrosion-resistant.

All forms of ferric chloride will cause bad stains. This staining will occur on almost every material including walls, floors, equipment and even operators.

Safety precautions required for handling ferric chloride in concentrated forms should be the same as those for acids. Wear protective clothing, face shields and gloves. Flush off all splashes on clothing and skin immediately.

4.103 Lime

Hydrated lime (calcium hydroxide or $Ca(OH)_2$) is used to coagulate solids or adjust the pH to improve the coagulation process of other chemicals. Lime may be purchased in 50- or 100-pound bags or in bulk truck or railroad car loads. Lime should be stored in a dry place to avoid absorbing moisture.

Lime also may be purchased as anhydrous or quicklime, but must be *SLAKED*[4] before using. Quicklime is more difficult to store because it will easily absorb moisture and cake. Quicklime is less expensive to purchase than lime; however, the added equipment for slaking and the requirement for increased operational safety must be considered.

Heat is generated when water is added to quicklime. If the controlled water supply fails and the water is shut off while the lime feed continues, boiling temperatures can be reached quickly. If a boiling reaction results, hot lime may cause the slaker to erupt and spew out hot lime. If high temperature controls are properly installed, they should activate an alarm and/or shut down the unit. Mixers and pumps should be inspected frequently (daily) for wear because the lime slurry will rapidly erode or wear moving parts.

When transporting concentrated lime slurries in pipelines, a scale will build up on the inside of the pipe and eventually plug the line. A 2- to 3-inch (50 to 60 mm) diameter pipe may need replacing every year or two due to this scale. Rubber or flexible piping with easy access and short runs will permit cleaning by squeezing the walls and washing out the broken scale. Standby lines should be provided for use during the cleaning operation.

Lime is irritating to the skin, the eyes, the mucous membranes and the lungs. Protect your eyes and lungs with safety equipment and wear protective clothing when working around lime.

4.104 Polymeric Flocculants

Polymeric flocculants are high-molecular-weight organic compounds with the characteristics of both polymers and *ELECTROLYTES*[5]. They are commonly called *POLYELECTROLYTES*[6]. These flocculants may be of natural or synthetic origin. Polyelectrolytes are classified on the basis of the type of charge on the polymer chain. Negative-charged polymers are called "anionic" and positive-charged polymers are called "cationic." Polymers carrying no electrical charge are called "nonionic polyelectrolytes."

A great assortment of polyelectrolytes is available to the wastewater plant operator. They may be applied alone or in combination with other chemicals to aid coagulation. With this large selection of polymers available, it is possible to find a beneficial combination for almost all conditions. Because of this selection, extensive laboratory testing should be conducted before treating the entire plant effluent. Most polyelectrolyte suppliers have field representatives who will assist with the testing of their products at the treatment plant.

Polyelectrolytes are commonly used in very small doses, usually less than 1 mg/*L*. The effective dosage range is limited. An overdose can be worse than no polymer addition at all.

Polyelectrolytes are available as a dry powder or as a liquid. Care must be taken when storing powders because they may quickly absorb moisture and become ineffective.

Solutions for treating wastewater are made up from powders in a batch tank and fed from a separate tank. When mixing a batch, care is required to add the powder slowly while continuously mixing. If care is not taken, useless lumps will form that can clog feed pumps and lines.

Polyelectrolytes are considered non-hazardous to handle; however, good housekeeping must be practiced because polyelectrolytes will create an extremely slippery surface when wet. Clean up spills immediately! Chlorine will break down a polyelectrolyte. To clean up a spill, neutralize the polyelectrolyte with either salt (NaCl), liquid bleach or HTH powder. This procedure may be used with any type of polyelectrolyte. Some polyelectrolytes have a low pH and can be corrosive to the make-up day or age tank (tank used to store solution).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 331 and 332.

4.1F What safety precautions are required for handling ferric chloride in concentrated solutions?

4.1G How can the scale of lime that builds up on the inside of pipe be cleared?

4.1H What problems can be created when a polyelectrolyte is spilled?

4.1I How would you clean up a polyelectrolyte spill?

---

[3] *Anhydrous (an-HI-drous). Very dry. No water or dampness is present.*

[4] *Slake. To become mixed with water so that a true chemical reaction takes place, such as in the slaking of lime.*

[5] *Electrolyte (ELECT-tro-LIGHT). A substance which dissociates (separates) into two or more ions when it is dissolved in water.*

[6] *Polyelectrolyte (POLY-electro-light). A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."*

4.11 Chemical Mixing Equipment

Chemical mixing equipment (Figure 4.3) is needed to prepare a solution of known concentration that can be metered (measured) into the water being treated. Polyelectrolytes can be difficult to dissolve. Also polyelectrolytes may need a period of aging prior to application. A dissolving tank with a mechanical mixer is used to prepare the solution for feeding. The resulting solution is stored in a day tank (holding tank) from which it is metered out at the proper dosage into the water being treated.

4.12 Chemical Feed Equipment

Chemical feeders (metering equipment) are required to accurately control the desired dosage. The chemical to be used and the form in which it will be purchased must be determined first because chemicals used for solids removal in wastewater treatment usually can be purchased in either solid or liquid form.

After metering, solid chemicals are generally converted into a solution or a slurry prior to applying to the wastewater stream. Both slurries and liquids often have flushing water used to rapidly carry the chemical to the point of application.

4.120 Types of Chemical Metering Equipment

To maintain accurate feed rates there cannot be any slippage in the metering equipment; therefore, most liquid feeders are of the positive displacement type. The quality of the water used for both mixing and flushing the polymer system is important. Poor quality plant effluent may cause clumps ("fish eyes") to form which will plug feeders, small orifices and even piping.

POSITIVE DISPLACEMENT PUMPS

A piston pump (Figure 4.4) is used for metering chemicals due to the accuracy of the positive displacement stroke and the ease of adjusting the piston stroke to regulate the chemical feed rate. With each stroke a fixed amount or volume of chemical or solution is discharged. By knowing the amount discharged per stroke and the number of strokes per minute, it is easy to calculate the chemical output.

Other positive displacement pumps besides the piston pump include the gear pump (Fig. 4.4) and the diaphragm pump (Figs. 4.5 and 4.6). Each of these pumps will produce a constant chemical flow rate for a specific setting.

The feed rate for dry chemicals must also be chemically controlled. Typical dry chemical feeders include the screw feeder, vibrating trough, rotating feeder, and belt-type gravimetric feeder.

SCREW FEEDER

A screw feeder unit maintains a desired output by varying the speed and/or the amount of time the screw rotates as it moves chemicals out the discharge port. Care must be taken that the chemical doesn't cake up in the hopper and stop feeding the screw. Also, the screw must be kept clean or the amount discharged per revolution will change (Fig. 4.7).

VIBRATING TROUGH FEEDER

The vibrating trough maintains a constant depth of chemical discharged and controls its chemical output by the magnitude and the length of time of the vibrations.

Care must be taken that the chemical doesn't cake in the hopper and stop feeding into the trough. Also, caking on the trough will prevent an even flow of chemical which could change the output volume.

ROTARY FEEDER

Rotary feeders are similar to the positive displacement gear pump because a fixed amount of chemical is discharged from between each tooth (Fig. 4.8). The output can be controlled by the speed and/or running time of the rotor. Care must be taken to maintain the rotor lobes clean and free of buildup that will change the chemical output volume.

BELT-TYPE GRAVIMETRIC FEEDER

A gravimetric belt feeder (Fig. 4.9) maintains a constant chemical weight on a revolving belt. This is accomplished using a vibrating trough and a balance system. The chemical output is controlled by the amount of chemical on the belt and the speed and time the belt travels. The amount of chemical is varied by the opening or closing of a feed gate or as a weighing deck moves up or down.

Care must be taken with this unit to assure that chemicals don't buildup on the balance because this will change the chemical output. By catching and weighing the chemical discharged at a constant speed over a measured amount of time, the feeder output can be calculated.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.1J How are chemical solutions prepared for feeding?

4.1K List the most common types of chemical feeders or metering equipment.

4.121 Selecting a Chemical Feeder

When you must decide which chemical feeder to purchase for your situation, include the following considerations:

1. *TOTAL OPERATING RANGE*

   Will the unit run at today's lowest expected chemical output as well as the future required output?

2. *ACCURACY*

   Will the unit maintain the same feed rate after it has been installed, calibrated and operated?

3. *REPEATABILITY*

   Can you return to previous settings and obtain the same feed rates as before?

4. *RESISTANCE TO CORROSION*

   Will the equipment, including electrical components, withstand the corrosive environment to which they may be exposed?

5. *DUST CONTROL*

   Is a means provided to control dust if needed?

6. *AVAILABILITY OF PARTS.*

   Are replacement parts readily available?

7. *SAFETY*

   Is the system designed with safety of both operation and maintenance in mind?

8. *ECONOMICS*

   Costs of purchase, installation, operation, maintenance, replacement and energy requirements.

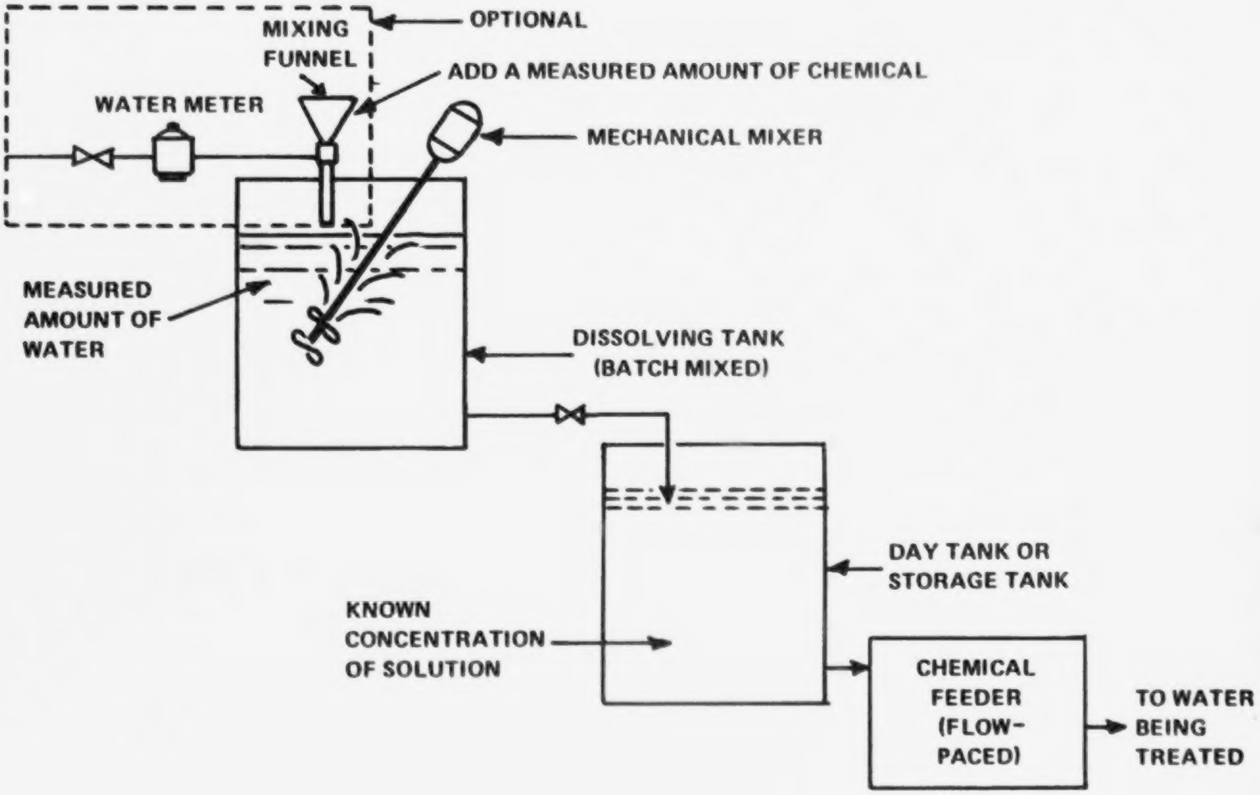
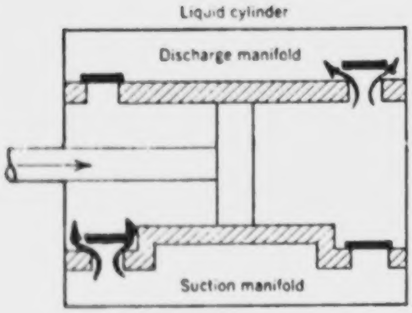
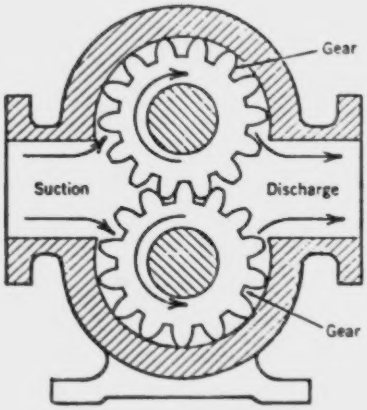

OPTIONAL
MIXING FUNNEL
ADD A MEASURED AMOUNT OF CHEMICAL
WATER METER
MECHANICAL MIXER
MEASURED AMOUNT OF WATER
DISSOLVING TANK (BATCH MIXED)
DAY TANK OR STORAGE TANK
KNOWN CONCENTRATION OF SOLUTION
CHEMICAL FEEDER (FLOW-PACED)
TO WATER BEING TREATED

Fig. 4.3 Dry chemical dissolver, day tank and feeder.


Liquid cylinder
Discharge manifold
Suction manifold

PISTON PUMP


Gear
Suction
Discharge
Gear

GEAR PUMP

Fig. 4.4 Piston and gear pump
(Courtesy of Chemical Engineering, 76 8, 45 (April 1969))

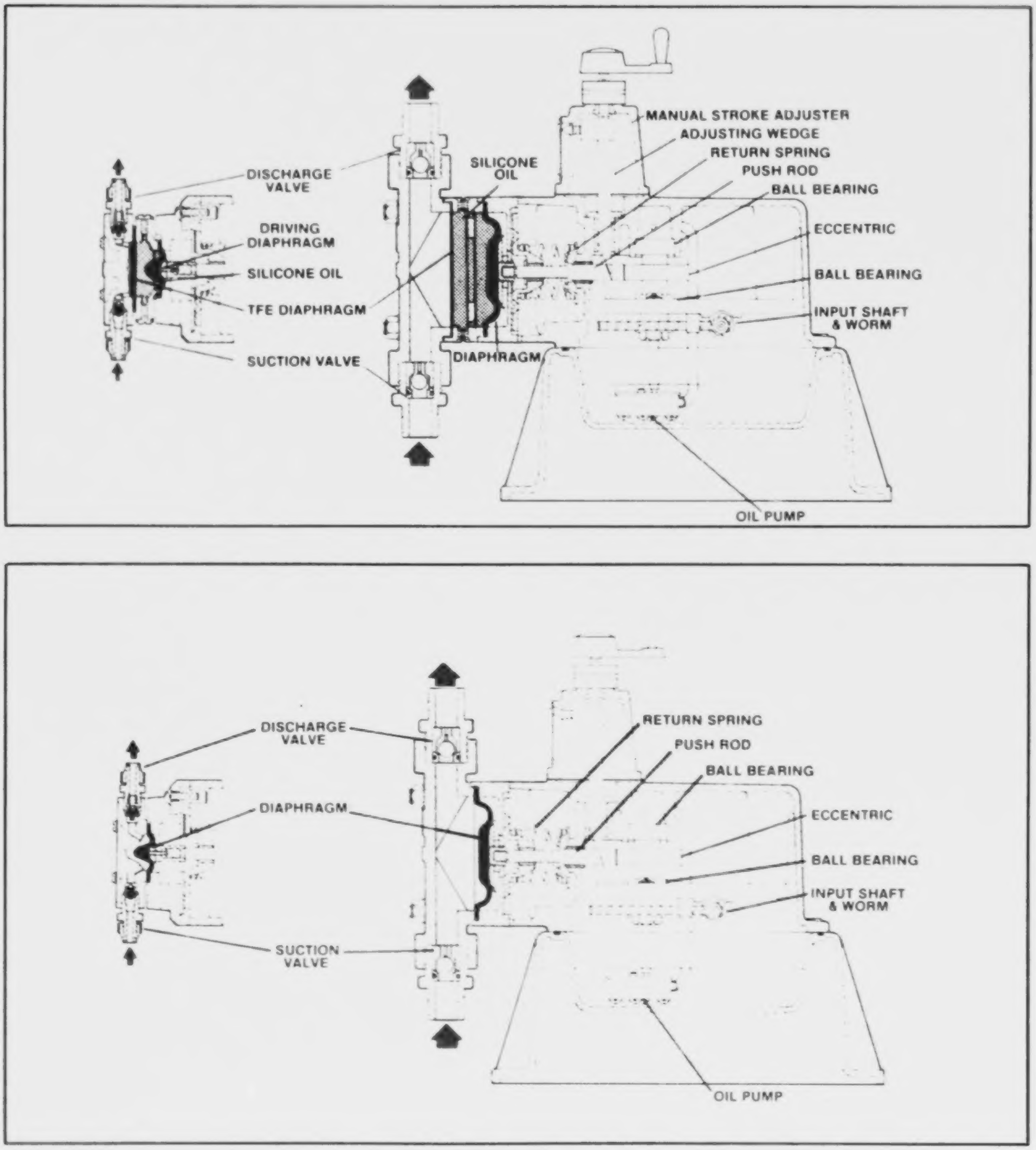

MANUAL STROKE ADJUSTER
ADJUSTING WEDGE
RETURN SPRING
PUSH ROD
BALL BEARING
DISCHARGE VALVE
SILICONE OIL
DRIVING DIAPHRAGM
SILICONE OIL
ECCENTRIC
BALL BEARING
TFE DIAPHRAGM
INPUT SHAFT & WORM
SUCTION VALVE
DIAPHRAGM
OIL PUMP
RETURN SPRING
DISCHARGE VALVE
PUSH ROD
BALL BEARING
DIAPHRAGM
ECCENTRIC
BALL BEARING
INPUT SHAFT & WORM
SUCTION VALVE
OIL PUMP

Fig. 4.5 Positive displacement diaphragm pumps

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

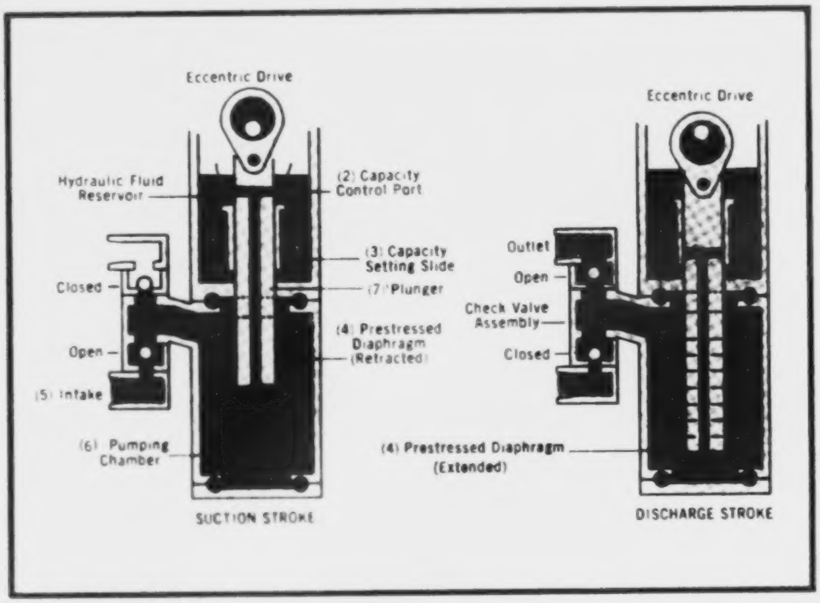

Eccentric Drive
Hydraulic Fluid Reservoir
(2) Capacity Control Port
(3) Capacity Setting Slide
Closed
(7) Plunger
(4) Prestressed Diaphragm (Retracted)
Open
(5) Intake
(6) Pumping Chamber
SUCTION STROKE
Eccentric Drive
Outlet
Open
Check Valve Assembly
Closed
(4) Prestressed Diaphragm (Extended)
DISCHARGE STROKE

Fig. 4.6 Positive displacement diaphragm metering

(Permission of BIF, a Unit of General Signal)

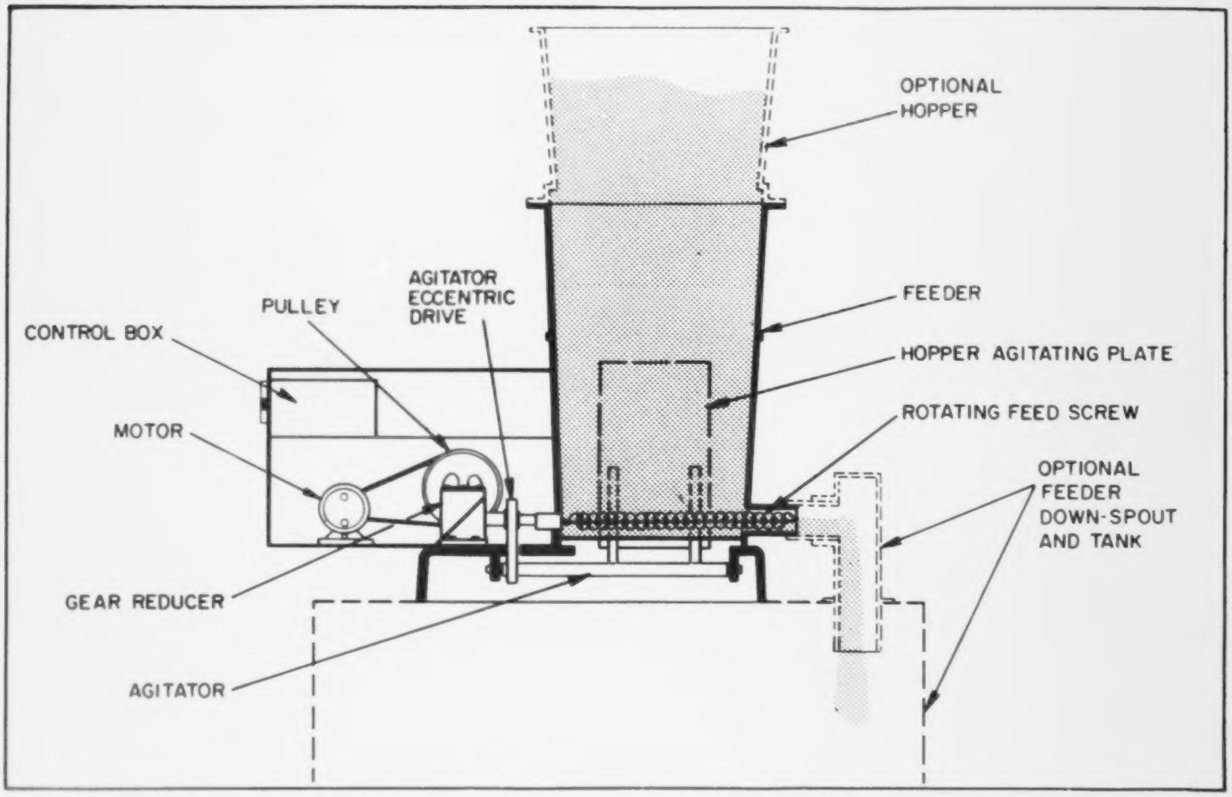

OPTIONAL HOPPER
FEEDER
HOPPER AGITATING PLATE
ROTATING FEED SCREW
OPTIONAL FEEDER DOWN-SPOUT AND TANK
AGITATOR ECCENTRIC DRIVE
PULLEY
CONTROL BOX
MOTOR
GEAR REDUCER
AGITATOR

Fig. 4.7 Volumetric screw feeder

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

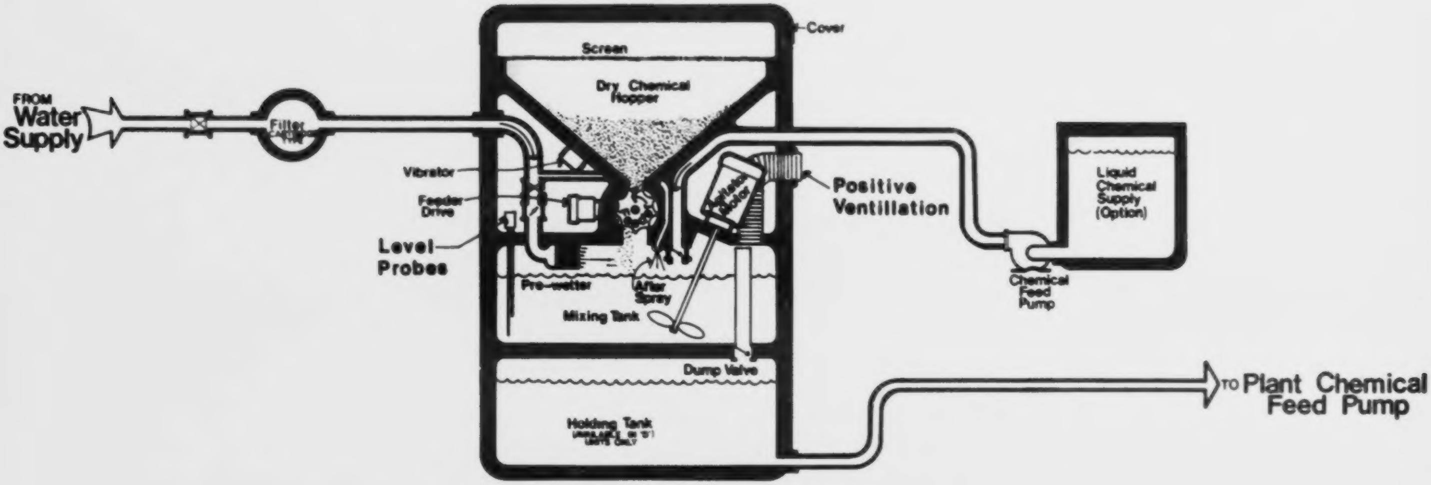

Cover
Screen
Dry Chemical Hopper
FROM Water Supply
Filter
Vibrator
Feeder Drive
Level Probes
Positive Ventilation
Liquid Chemical Supply (Option)
Chemical Feed Pump
Pre-wetter
After Spray
Mixing Tank
Dump Valve
Holding Tank
TO Plant Chemical Feed Pump

Fig. 4.8 Rotary feeder

(Permission of Neptune Microfloc)

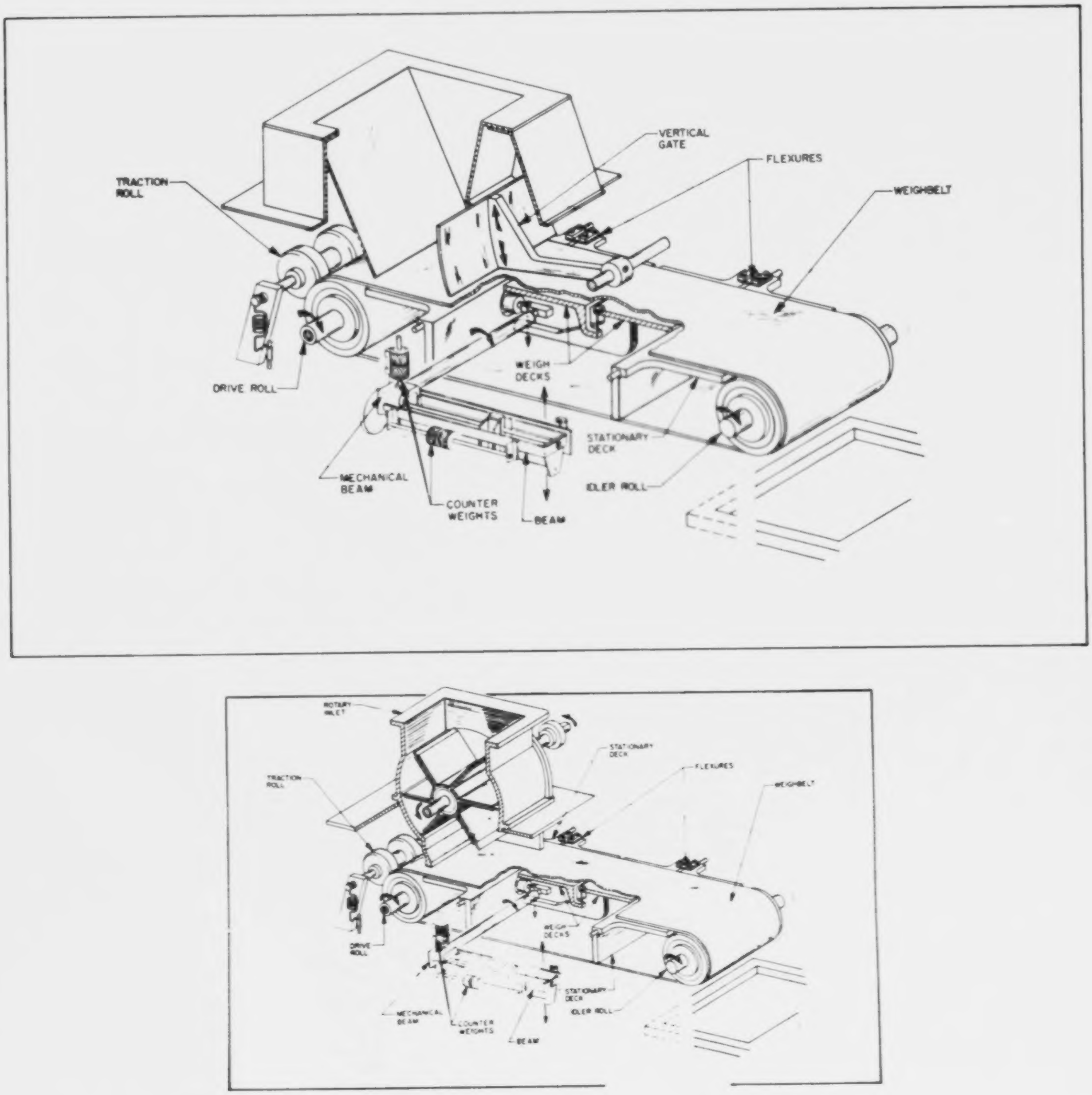

VERTICAL GATE
FLEXURES
WEIGHBELT
TRACTION ROLL
DRIVE ROLL
WEIGH DECKS
STATIONARY DECK
MECHANICAL BEAM
COUNTER WEIGHTS
BEAM
IDLER ROLL
ROTARY INLET
STATIONARY DECK
FLEXURES
WEIGHBELT
TRACTION ROLL
DRIVE ROLL
WEIGH DECKS
STATIONARY DECK
MECHANICAL BEAM
COUNTER WEIGHTS
IDLER ROLL
BEAM

Fig. 4.9 Gravimetric belt feeders

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

4.122 Reviewing Chemical Feed System Designs

When reviewing chemical feeding system designs and specifications, the operator should check the following items:

1. Review the results of pre-design tests to determine the chemical feed rate for both the present and future. The chemical feeders should be sized to handle the full range of chemical doses or provisions should be made for future expansion.
2. Determine if sampling points are provided to measure chemical feeder output.
3. Be sure provisions are made for standby equipment in order to maintain uninterrupted dosages during equipment maintenance.
4. Look for *ADEQUATE VALVING* to allow bypassing or removing equipment for maintenance without interrupting the chemical dosage.
5. Examine plans for valving to allow flushing the system with water before removing from service.
6. Be sure corrosion resistant drains are provided to prevent chemical leaks from reaching the floor; for example, drips from pump packing.
7. Check for corrosion-resistant pumps, piping, valves, and fittings as needed.
8. Determine amount of maintenance required. The system should require a minimum of maintenance. Equipment should be standard, with replacement parts readily available.
9. Consider the effect of changing head conditions, both suction and discharge, on the chemical feeder output. Changing head conditions should not affect the output if the proper chemical feeder has been specified.
10. Determine whether locations for monitoring readouts and dosage controls are convenient to the operation center and easy to read and record.

4.123 Chemical Feeder Start-Up

After the chemical feed system has been purchased and installed, the operator must carefully check it out before starting it up. Even if the contractor that installed the system is responsible for insuring that the equipment operates as designed, the operation by plant personnel, the functioning of the equipment, and the results from the process are the responsibility of the chief operator. Therefore, before start-up, check the following items:

1. Inspect the electrical system for proper voltage, for properly sized overload protection, for proper operation of control lights on the control panel, for proper safety lock-out switches and operation and for proper equipment rotation.
2. Confirm that the manufacturer's lubrication and start-up procedures are being followed. Equipment may be damaged in minutes if it is run without lubrication.
3. Examine all fittings, inspection plates and drains to assure that they will not leak when placed into service.
4. Determine the proper positions for all valves. A positive displacement pump will damage itself or rupture lines in seconds if allowed to run against a closed valve or system.
5. Be sure that the chemical to be fed is available. A progressive cavity pump will be damaged in minutes if it is allowed to run dry.
6. Inspect all equipment for binding or rubbing.
7. Confirm that safety guards are in place.
8. Examine the operation of all auxiliary equipment including the dust collectors, fans, cooling water, mixing water, and safety equipment.
9. Check the operation of alarms and safety shutoffs. If it is possible, operate these devices by manually tripping each one. Examples of these devices are alarms and shutoffs for high water, low water, high temperature, high pressure, and low chemical levels.
10. Be sure that safety equipment, such as eyewash, drench showers, gas masks, face shields, gloves and vent fans, is in place and functional.
11. Record all important nameplate data and place it in the plant files for future reference.

4.124 Chemical Feeder Operation

Once the chemical feed equipment is in operation and the major "bugs" are worked out, the feeder will need to be "fine tuned." To aid in fine tuning and build confidence in the entire chemical feed system, the operator must maintain accurate records (Figures 4.10 and 4.11). These records will include the flows and characteristics of the waste before treatment, the dosage and conditions of the chemical treatment, and the results obtained after treatment. A comment section should be used to note abnormal conditions, such as a feeder plugged for a short time, a sudden change in the characteristics of the influent waste, and related equipment that malfunctions. Daily logs should be summarized into a form that operators can use as a future reference.

4.125 Shutting Down Chemical Systems

If the equipment is going to be shut down for an extended length of time, it should be cleaned out to prevent corrosion and/or the solidifying of the chemical. Lines and equipment could be damaged when restarted if chemicals left in them solidify. Operators could be seriously injured if they open a chemical line that has not been properly flushed out.

The following items should be included in your checklist for shutting down the chemical system:

1. Shut off the chemical supply,
2. Run dry chemicals completely out of the equipment and clean equipment,
3. Flush out all the solution lines,
4. Shut off the electrical power,
5. Shut off the water supply and *PROTECT FROM FREEZING*, and
6. Drain and clean the mix and feed tanks.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.1L List the items that should be considered when selecting a chemical feeder.

4.1M What information should be recorded for a chemical feeder operation?

SODIUM HYDROXIDE LOG

	TANK #1 GAL.	TANK #2 GAL.	TANK #3 GAL.	GAL. #3 BEFORE TRANS.	GAL. #3 AFTER TRANS.	H_2O TO NAOH	DILUTE GAL. USED	TOTAL GAL REC.	REMARKS
1	880	-0-	1280				300		
2	880	-0-	990				290		
3	880	-0-	700				290		
4	880	-0-	580				120		
5	880	-0-	300				280		
6	-0-	-0-	1840	200	2000	1-1	260		
7	-0-	-0-	1600				240		
8	-0-	-0-	1400				200		
9	-0-	-0-	1240				160	4,000	
10	1990	1940	1050				190		
11	1990	1940	850				200		
12	1990	1940	650				200		
13									
14									
15									
16									
17									
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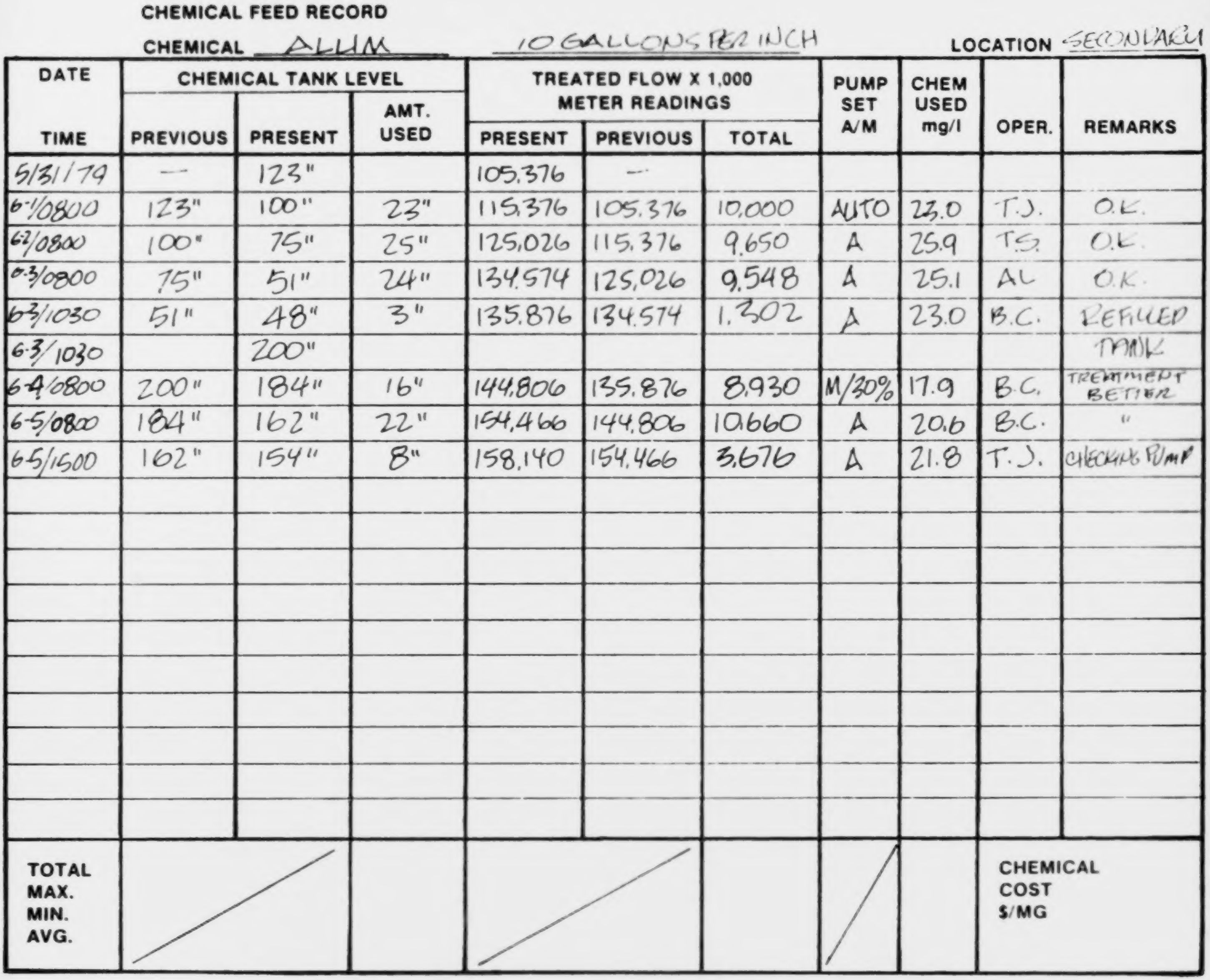
22									
23									
24									
25									
26									

Fig. 4.10 Typical record of chemical feeder operation



CHEMICAL FEED RECORD

CHEMICAL ALUM 10 GALLONS PER INCH LOCATION SECONDARY

DATE TIME	CHEMICAL TANK LEVEL			TREATED FLOW X 1,000 METER READINGS			PUMP SET A/M	CHEM USED mg/l	OPER.	REMARKS
	PREVIOUS	PRESENT	AMT. USED	PRESENT	PREVIOUS	TOTAL				
5/31/79	—	123"		105.376	—					
6-1/0800	123"	100"	23"	115.376	105.376	10,000	AUTO	23.0	T.J.	O.K.
6-2/0800	100"	75"	25"	125,026	115.376	9.650	A	25.9	T.S.	O.K.
6-3/0800	75"	51"	24"	134.574	125,026	9,548	A	25.1	AL	O.K.
6-3/1030	51"	48"	3"	135.876	134.574	1,302	A	23.0	B.C.	REFILLED
6-3/1030		200"								TANK
6-4/0800	200"	184"	16"	144,806	135.876	8,930	M/30%	17.9	B.C.	TREATMENT BETTER
6-5/0800	184"	162"	22"	154,466	144.806	10,660	A	20.6	B.C.	"
6-5/1500	162"	154"	8"	158,140	154.466	3,676	A	21.8	T.J.	CHECKING PUMP
TOTAL MAX. MIN. AVG.									CHEMICAL COST $/MG	

Fig. 4.11 Typical form for chemical feeder operation

4.13 Determining Chemical Dosage

The proper chemical dosage is very important. A slight amount over or under the optimum is often worse than not adding chemicals at all. A combination of two or more chemicals will often result in improved treatment and reduced overall costs.

The wastewater entering the system may change composition from weekdays to weekends, from season to season, or from year to year. Because of these variations, the operator must carefully observe the efficiency of the chemical treatment.

When chemicals are added to reduce the effluent suspended solids, the operator should daily:

1. Run suspended solids tests on influent and effluent,
2. Calculate suspended solid removal efficiency,
3. Calculate chemical dosage,
4. Run turbidity tests on effluent,
5. Observe visual appearance of effluent, and
6. Maintain complete records.

4.130 Jar Test (Figure 4.12)

The most common method used to determine coagulation dosages is the jar test. The jar test is an attempt to duplicate plant conditions by using laboratory equipment. Jar tests can be misleading unless they reflect actual plant suspended solids conditions. Be sure to run jar tests on samples of the water to be treated. For example, a plant is adding metal salts for phosphorus removal (Chapter 5) and a polymer for suspended solids control to the effluent from an activated sludge aeration tank. Before the type of polymer and dose can be determined, you will have to build up the metal hydroxy phosphate precipitate in the activated sludge system to "steady-state" or "equilibrium" conditions.

Equal amounts of influent samples (usually 500 to 1,000 ml) to be treated are set up a gang stirrer (Figure 4.12) for the jar test. Chemicals are added in varying doses and all portions of the sample are rapidly mixed. After rapid mixing, the samples are slowly mixed to approximate the conditions in the plant. Mixing is then stopped and the floc formed is allowed to settle. The appearance, the time to form a floc, and the settling conditions are recorded. The supernatant (liquid above the settled sludge) is analyzed for turbidity, suspended solids and pH. With this information the operator selects the best dosage to feed on the basis of clarity of effluent and minimum cost of chemicals.

4.131 Procedure for Plants Without Laboratory Facilities

Source: *PROCEDURE FOR DETERMINING THE ALUM DOSAGE* Permission of Industrial Chemicals Division, Allied Chemical Corporation, Solvay, New York

In case a laboratory is unavailable, it is possible to maintain reasonable control by conducting coagulation tests by means of a simple hand-stirring method.

Clear glass fruit jars, one- to two-quart capacity, are a good substitute for beakers and are easily obtainable. If necessary, the local druggist or high school chemistry teacher will usually assist in preparing alum solutions and lime suspensions. If a pipet is unavailable, a common medicine dropper will deliver approximately 20 drops to a ml. A calibrated dropper (1.0 ml) may be obtained from the drug store.

Procedure:

1. Dissolve 9.46 grams of alum and dilute to 1 liter (8.95 grams of alum to one quart). One ml of this solution will provide a treatment of 10 mg/*L* of alum when added to one quart (946 ml) of the water sample.
2. With the pipet or medicine dropper, add 1 ml of the alum solution to one quart of the sample and stir rapidly for approximately two minutes. Actual rapid mixing time should be similar to the actual detention time of the water being treated in the flash mixer. This actual detention time may vary from 50 seconds to six minutes depending on design and flows. Then stir gently for at least fifteen minutes to permit floc particles to grow. Again, this actual gentle mixing time should be similar to the actual process flocculation time. The speed of gentle mixing paddles in the jar test should be similar to the actual flocculator paddles. When running the jar test, try adjusting the paddle speed to produce the best floc particle growth and then operate the flocculator paddles at this speed. Under some conditions the best floc can be produced by stopping the flocculators. Avoid violent agitation during this floc conditioning stage to prevent the breakup of the floc particle.
3. Observe the quality of the floc, the rate of settling, and the clarity of the settled water.
4. Repeat the above using a higher alum dose until the desired floc and clarity are achieved.

Helpful Factors:

1 liter = 1000 ml
1 quart = 946 ml
1 grain/gal = 17.1 mg/*L*
1 grain/gal = 143 lbs/million gallons
1 mg/*L* = 8.34 lbs/million gallons

4.132 Phosphate Monitoring

When the coagulant is being used to precipitate phosphate as well as to remove solids, coagulant dosage control may be obtained by automatically analyzing the incoming wastewater for soluble orthophosphate. The coagulant feeder is set to maintain a selected ratio of coagulant-to-phosphate either automatically or manually. Equipment is available that will automatically do this type of coagulant feeding.

Coagulant dosages that produce good phosphate removal will generally produce good solids removal if polymers are used to aid in flocculating the fine, precipitated matter. Usually the polymer feed should be flow-paced; however, the polymer feeder may function with manual adjustments.

4.14 Good Housekeeping

Good housekeeping is a part of the total plant operation. Good housekeeping around the chemical feed systems is very important to good operations and safety. A dry chemical feeder that weighs its output will change its feed rate if chemicals are allowed to build up on the scales. Good housekeeping will reduce the hazard of slipping around chemical handling areas and will keep the dust down in work areas. Good housekeeping is a daily duty and must not be neglected.

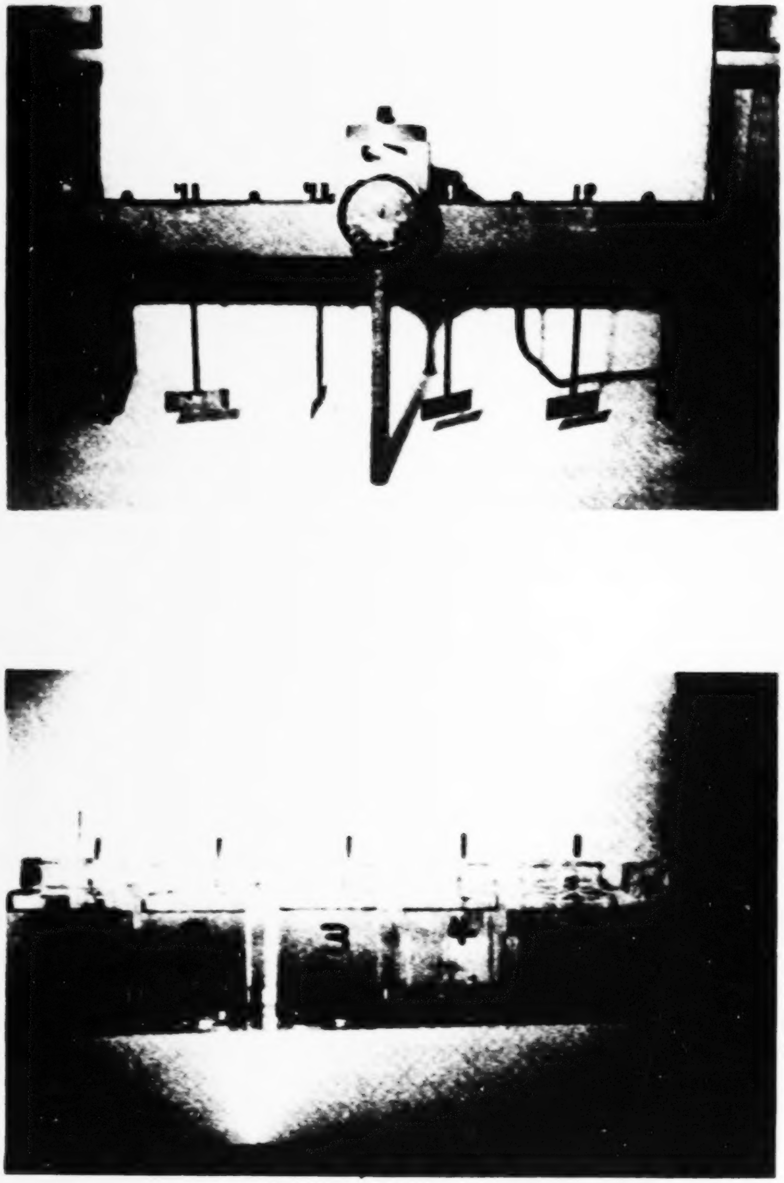


Fig. 4.12 Jar test units with mechanical (top) and magnetic (bottom) stirrers

(Source: EPA Process Design Manual for Suspended Solids Removal)

4.15 Safe Working Habits

Chemical feed equipment and chemical handling areas have safety hazards that each operator should become aware of for each plant. In addition to the usual electrical and mechanical hazards associated with automatic equipment, chemical feeding hazards include:

1. Strong acids,
2. Strong caustics,
3. High pressures,
4. High temperatures,
5. Dust in the air, and
6. Slippery walk areas.

Develop safe working habits by always wearing proper safety equipment and protective clothing.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.1N What factors can cause a change in chemical dose requirements?

4.1O How are coagulation dosages determined?

4.1P What is the jar test?

4.16 Operation

4.160 Operational Strategy

The development of an operational strategy for a chemical treatment process will prepare you to deal with sudden changes in the water being treated, to train new operators and to plan for the future. Items that should be considered in your strategy include:

1. The jar test is the most important control test for chemical treatment. Set up your laboratory so jar tests can be run quickly and easily. Accurate jar tests can result in significant chemical and cost savings. For example, if the dosage of a polyelectrolyte costing $2.00 per pound could be reduced by 0.5 mg/*L* in a 10 MGD plant, the cost savings would be $83.40 per day.
2. Monitor chemical feeders closely to assure proper output. New equipment should have actual feed rates measured and compared with feed settings at least weekly.
3. Adjust chemical dosages whenever the flow rate changes. Long detention times during low flows may not require as high a chemical dosage as shorter detention times during high flows.
4. Monitor water conditions and quality at least daily for alkalinity, pH, temperature, turbidity, and suspended solids because these water quality indicators may signal a need for a chemical dosage change. If you are removing phosphorous, measure soluble phosphorous also.
5. Consider in-plant conditions when collecting samples for jar tests and adjusting chemical dosages. For example, if one-half of the primary clarifiers in a plant are out of service or if a digester is upset, these situations can affect required chemical doses.

4.161 Abnormal Operation

This section contains a list of abnormal conditions that could occur at any time during the operation of a wastewater treatment plant. Included are recommendations that should help you adjust the chemical treatment system in order to maintain a high quality effluent.

1. High solids concentrations in effluent leaving the secondary clarifiers due to bulking sludge, rising sludge or solids washout.
   a. Inspect chemical feeders for proper output.
   b. Run jar tests to determine if dosage requirements have changed.
   c. Examine overall plant operations to locate cause of high solids.
   d. Increase sludge removal rates from clarifiers.

2. Low suspended solids in effluent leaving the secondary clarifiers.
   a. Inspect chemical feeders for proper output.
   b. Run jar tests to determine if dosage requirements have changed.
   c. Record in log book conditions and dosage that produced low solids in the effluent. You need to know how you produced a good quality effluent.

3. High flows passing through the treatment plant.
   a. Prepare to feed a greater quantity of chemicals.
   b. Run jar tests to determine dosage that will produce rapid settling rates because detention times are reduced.
   c. Be sure jar test flash mixing and flocculation times are similar to actual detention times through these units during the high flows.

4. Low flows passing through the treatment plant.
   a. Run jar tests to determine optimum dosage because longer detention times may allow a reduction in chemical dosage which will reduce chemical costs.
   b. Watch for chemical overdoses that could produce toxic conditions in biological treatment processes or in the receiving waters.

5. A change in the pH of the water being treated by one or more units.
   a. Inspect chemical feeders to determine if the chemicals being added are causing the pH change.
   b. Run jar tests to determine if chemical feed rates need adjusting.
   c. Extreme pH changes may affect biological activity and effectiveness of disinfection. Try to control chemical feeders to minimize chemical changes.
   d. If existing chemical dosages will not cause coagulation, new chemicals may be required. For example, you may have to switch from one type of polyelectrolyte to another type.

6. A change in water temperature resulting from seasonal weather conditions, groundwater infiltration and/or wet weather inflows.
   a. Run a jar test to determine if new chemical feed rates are required. Coagulation and settling rates change when the temperature changes.

4.162 Troubleshooting

PROBLEM: NO COAGULATION.

Inspect the following items:

1. Chemical feed pump operation,
2. Chemical supply and valve positions,
3. Solution carrier water flow and valve positions,
4. Applied water for a significant change,
5. Actual feeder output by catching a timed sample, and
6. Feed chemical strength.

Run a jar test to determine the proper dosage. Be sure the jar test chemicals are the proper strength.

PROBLEM: FOAMING.

Foam can develop in rapid-mix tanks and flocculators. Control foam by the use of water spray from hoses or surface spray nozzles.

4.17 Maintenance

All equipment maintenance must be performed in accordance with manufacturers' instructions. Good housekeeping is very important whenever working with chemicals. Chemical feed pumps and bottom sludge pumps must be periodically disassembled and cleaned. Weir plates, baffles and drains must be kept clean to maintain proper basin hydraulics. Weir crests must always be kept clean. Motors, drive systems and paddles will require servicing and repair. Frequency and type of maintenance and repair will depend on housekeeping, chemicals and equipment.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.1Q What water quality indicators should be monitored when operating a chemical treatment process?

4.1R What abnormal conditions could be encountered in the water being treated when operating a chemical treatment process?

4.1S List two problems that could occur when operating a chemical treatment process.

END OF LESSON 1 OF 4 LESSONS
ON
SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

DISCUSSION AND REVIEW QUESTIONS

(Lesson 1 of 4 Lessons)

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. Why do some NPDES permits impose stringent discharge requirements on some treatment plants?
2. What precautions should be taken when using alum to improve the settling of solids?
3. Why should extensive laboratory testing be conducted before treating a secondary effluent with a polyelectrolyte to remove solids?
4. Why are positive displacement pumps used for metering chemicals?
5. What economic factors should be considered when selecting a chemical feeder?
6. Why should chemical feed equipment be cleaned before being shut down for an extended length of time?
7. Explain how to run the jar test.
8. Why should you develop an operational strategy for a chemical treatment process?

CHAPTER 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

(Lesson 2 of 4 Lessons)

4.2 SOLIDS REMOVAL FROM SECONDARY EFFLUENTS USING MICROSCREENS (Also see Chapter 6, Section 6.2, "Screening and Microscreening Applied to Industrial Wastes" in *INDUSTRIAL WASTE TREATMENT*

Microstraining is a form of filtering used to clarify water by filtering out very small suspended solids. The process involves passing water through a very finely woven fabric called microfabric (Figure 4.13). Microfabric is usually made of stainless steel wire, plastic, polyester or nylon cloth. The polyester or nylon microfabric can be manufactured with openings as small as 1.0 microns (0.00004 inch) in size.

The filtered solids quickly build up a mat on the screen, thereby removing particles smaller than the actual openings of the fabric as the water passes through the mat.

The microfabric is attached to the outside of a drum. The applied water flows into the drum through one end and out through the wall (Figures 4.14 and 4.15). The solids remain inside the drum because they cannot pass through the microfabric. To prevent clogging of the microfabric, the drum is rotated and the mat of solids is washed off by a water spray system. The cleaned fabric rotates back into the process stream again in a continuous operation.

The solids are washed into a hopper inside the drum and carried back into the system for retreatment. These solids may be returned to the primary clarifier or they can be disposed of by thickening and pressing (Chapter 3) before ultimate disposal to landfill, incineration or byproduct recovery depending on the type of solids.

The process of microstraining is capable of:

1. Reducing the organic loading on the receiving waters,
2. Removing particles from the effluent,
3. Reducing the coliform group organisms in the water being treated,
4. Improving the effectiveness of the disinfectant,
5. Lowering the turbidity level, and
6. Improving the overall appearance of the effluent.

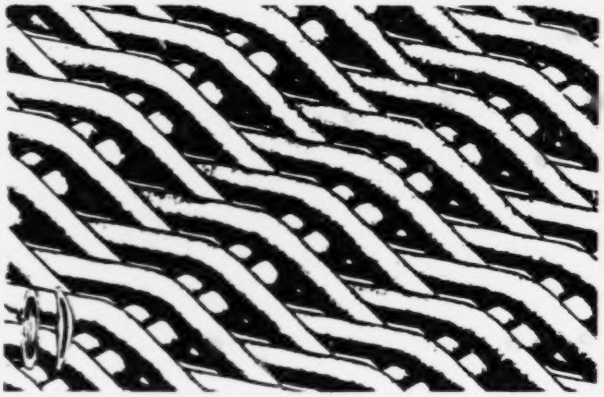


Fig. 4.13 Isometric drawing of microfabric with typical diatom shown against the fabric

(Permission of Crane Co.)

Important features of these units include:

1. They can be installed where space is limited,
2. They operate under open, gravity-flow conditions in concrete tanks or packaged steel tank units, and
3. They will operate with a minimal amount of manpower.

Microscreens added to existing treatment plants will affect other plant systems. The operator must be prepared to make the necessary adjustments to compensate for this problem. The solids leaving the plant in the effluent will be less; therefore the solids handling equipment will have an increased loading. This results in more sludge to pump, dewater, digest, and dispose of as a solid.

The water sprays cleaning the microfabric will add a flow load of from one- to five-percent of the influent flow to the treatment system.

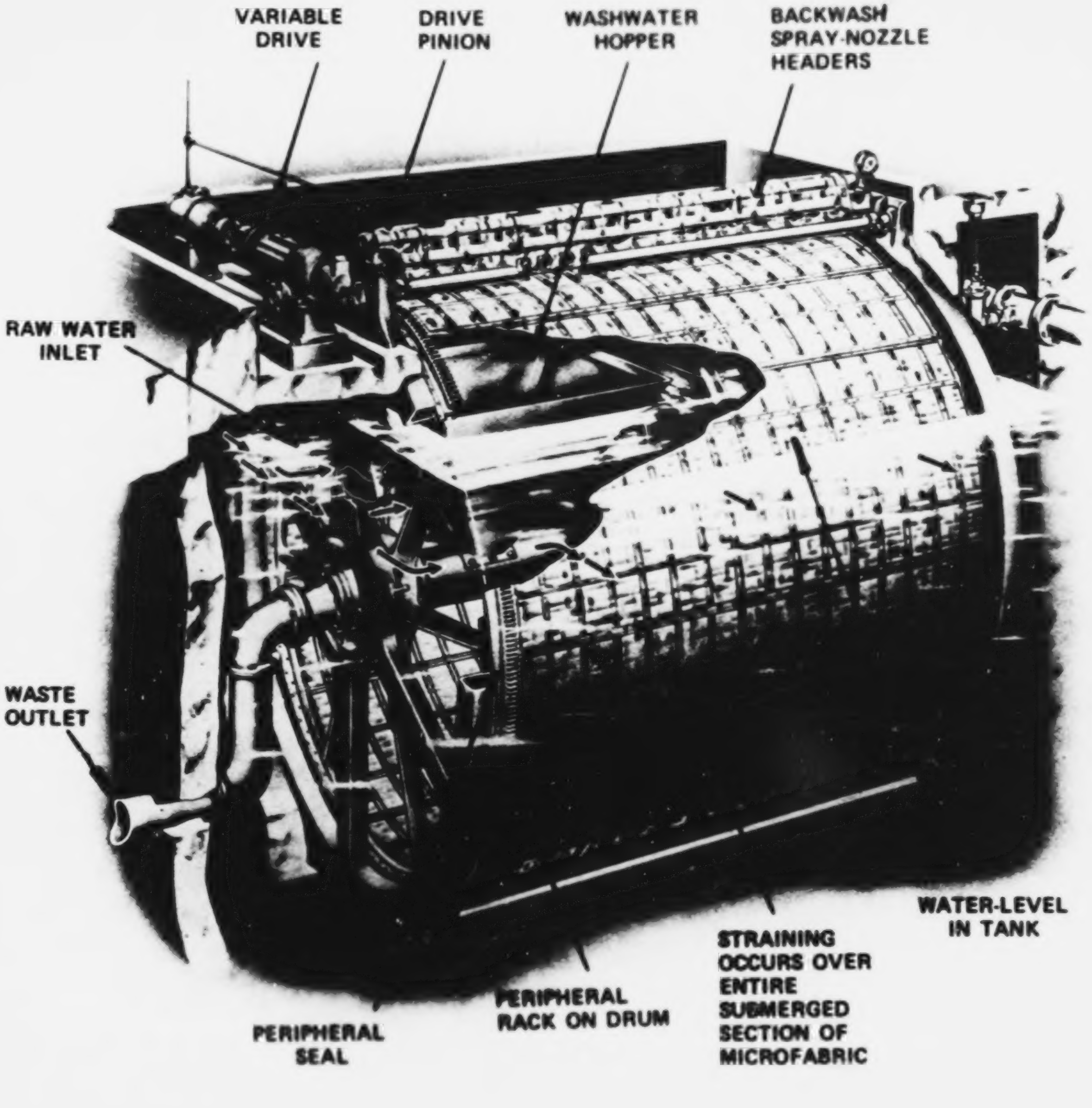

VARIABLE DRIVE
DRIVE PINION
WASHWATER HOPPER
BACKWASH SPRAY-NOZZLE HEADERS
RAW WATER INLET
WASTE OUTLET
WATER-LEVEL IN TANK
STRAINING OCCURS OVER ENTIRE SUBMERGED SECTION OF MICROFABRIC
PERIPHERAL RACK ON DRUM
PERIPHERAL SEAL

Fig. 4.14 Microscreen

(Permission of Crane Co.)

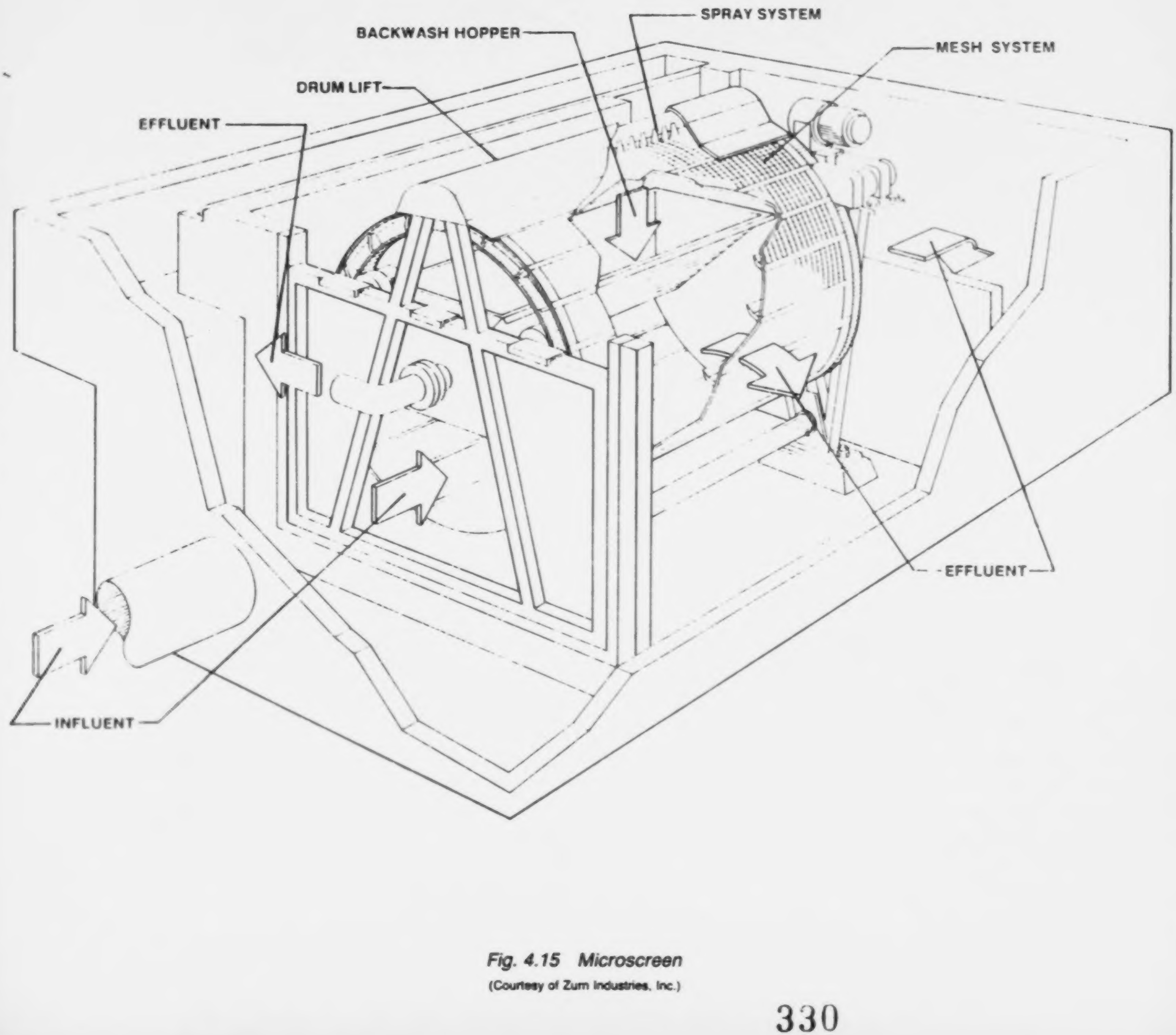

SPRAY SYSTEM
BACKWASH HOPPER
MESH SYSTEM
DRUM LIFT
EFFLUENT
EFFLUENT
INFLUENT

Fig. 4.15 Microscreen

(Courtesy of Zurn Industries, Inc.)

Plant staff may have to be increased to meet the need for additional labor to properly maintain and service microscreen units.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.2A What is microstraining?

4.2B What materials are generally used to manufacture microfabric?

4.20 Components of a Typical Microscreen

4.200 Drum

The drum is the main physical structure of the microscreen unit. This drum provides the frame around which the microfabric is attached. Drum diameters range from 5 to 10 feet (1.5 to 3.0 meters) in diameter and 1 to 10 feet (0.3 to 3.0 meters) in length. The drum operates with about 70 percent of its surface area submerged. This keeps a large area of the microfabric in the process flow.

4.201 Microfabric

The microfabric physically separates the solids from the water leaving the unit. The microfabric openings are extremely small. They are in the range of 1 to 60 microns. To get an idea of the size of an opening, a 60-micron fabric has about 60,000 openings per square inch and a 23-micron fabric has about 165,000 openings per square inch.

Microfabric is usually made of woven stainless steel or plastic. The plastic is used for the smaller openings and is less subject to chemical attack by chlorine or acid cleaning solutions. The stainless steel can better withstand steam cleaning used to remove grease and oil. Manufacturers will design and provide microfabric for each special application.

Microfabric is supplied either in small sections (8 in × 12 in or 20 cm × 30 cm) or in larger (18 in × 24 in or 45 cm × 60 cm) panels. The small sections are supported by and fastened directly to the drum frame while the panels have a supporting mesh of stainless steel bonded to the fabric.

Standard design calls for a 1 foot (30 cm) head loss at average flows and 2 feet (60 cm) head loss for normally expected maximum flows. Occasional peak head losses of 4 feet (120 cm) can be tolerated. One manufacturer indicates that stainless steel microfabric operated with a head loss of 3 inches (7.5 cm) under average conditions would have a life of 10 years; while the same fabric operated continuously at 24-inch (60 cm) head loss might last only 6 months.

Any flexing or movement of the fabric as it passes in and out of the process water will shorten its life. Chlorine in the process water and strong cleaning acid will also shorten the life of the microfabric.

4.202 Water Spray System

Water spraying on the outside of the drum as it reaches the highest point provides continuous backwashing of the microfabric. Water pressures ranging from 15 to 60 psi (1 to 4 kg/sq cm) are used with generally better results obtained using the higher pressures. Water consumption for backwashing varies from 1 to 5 percent of the flow through the filter.

4.203 Solids Waste Hopper

The hopper is located inside the revolving drum and catches the solids washed from the microfabric. Removed solids are returned to the primary treatment system and reprocessed or they may be disposed of by thickening and pressing before ultimate disposal to landfill, incineration or byproduct recovery.

4.204 Support Bearings

Support bearings may be water-lubricated axial or grease-lubricated bearings located on the upper inside surface of the rotating drum. Both types of bearings will allow the operating water level to be above the drum center line. These bearings require careful maintenance in accordance with the manufacturer's recommendations to prevent early failure.

4.205 Drum Drive Unit

The drum rotational speed may be adjusted manually or automatically in relation to the flow or head loss in the unit. Optimum speed will be determined with experience and usually does not require frequent adjustment.

4.206 Ultraviolet Lights

Ultraviolet (UV) lights are used to reduce biological growths on the microfabric. These growths can survive the water spray cleaning and will eventually clog the fabric. Ultraviolet lights reduce the manhours required to clean the microfabric with special washes. Ultraviolet light is *EXTREMELY* dangerous to the eyes. All plant staff must be aware of the dangers and protect their eyes.

4.207 Structure

The structure in which the microscreen unit is installed may be concrete or steel. Both need a good drain to permit easy dewatering and cleaning. A sloped bottom and a sump will aid in cleaning.

4.208 Bypass Weir

A bypass weir is needed to permit flows in excess of unit capacity to be bypassed. The manufacturer's recommended maximum head loss through the drum should never be exceeded to prevent damage to the microfabric.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.2C List the major components of a typical microscreen.

4.2D What is the purpose of ultraviolet lights used with a microscreening process?

4.21 Operation of Microscreens

4.210 Pre-Start Checklist

Before starting up any major piece of equipment, a thorough check of the system must be made to prevent damage to the equipment and injury to personnel. The following items should be included in your checklist for microscreens.

1. Be sure all debris from construction has been removed from the unit. Wood scraps and concrete chips can easily damage equipment, especially the microfabric.
2. Inspect the electrical installation for completeness. Be sure controls are properly covered, fuses properly sized, and proper safety lockouts have been installed.
3. Check motor and drives for proper alignment, for proper safety guards installed in place, and for free rotation of motor and drives.
4. Examine motors, drive units, bearings, and chain for proper lubrication.
5. Check motor for proper rotation.
6. Examine motor and drive unit for excessive vibration.
7. Study the operation of water sprays, ultraviolet lights and other auxiliary equipment for proper operation.
8. Inspect the entire unit for any safety hazards.

4.211 Normal Operation

Normal operation requires the operator to carefully follow the procedures outlined below.

1. Have the drum rotating when the process water first enters the microscreen or the fabric may plug and be damaged.
2. Open the inlet gates and start the drive motor, water sprays, lights and related equipment.
3. Maintain a log of the operation of the unit. Include the following items:
   a. Hours of operation,
   b. Volume of water processed, gallons or cubic meters,
   c. Rate of application, gpd or cu m/day,
   d. Applied suspended solids and BOD, lbs or kg/day,
   e. Effluent suspended solids and BOD, lbs or kg/day,
   f. Percent removal of suspended solids and BOD, %,
   g. Chemicals added, pounds or kilograms,
   h. Head loss through the screen, inches or centimeters,
   i. Maintenance performed on the unit, and
   j. Remarks of special observations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.2E Before starting a microscreen unit, what items would you inspect in the electrical installation?

4.2F What items should be included in the log of the operation of a microscreen?

4.212 Abnormal Operation

When operating a microscreen, be prepared to solve problems created by the abnormal conditions listed in this section.

PROBLEM: HIGH FLOWS

Problems caused by high flows include:

1. Excessive head loss (above 12 inches or 30 centimeters) through the microscreen (be sure to check manufacturer's recommendations),
2. Excessive solids in the microscreen effluent,
3. Plugging of the microfabric with solids and/or grease, and
4. Untreated water overflowing the microscreen bypass weir.

SUGGESTED CORRECTIVE ACTION

1. Increase the drum rotation speed.
2. Increase the water spray pressure.
3. Place additional units in service.
4. Hand clean the microfabric with a bactericide, hot water or steam.
5. Reduce the flow by using a *FLOW-EQUALIZATION SYSTEM*[7] or by storing the excess flow in the influent line until the flows drop.
6. Add chemicals to upstream processes to reduce the suspended solids loading by improving settling.

PROBLEM: LOW APPLIED WATER FLOWS

Problems caused by low applied flows include:

1. Lower suspended solids loadings, and
2. Thinner mat buildup on microfabric. This thinner mat may reduce filtering effectiveness.

SUGGESTED CORRECTIVE ACTION

1. Reduce the drum rotation speed.
2. Reduce the water level within the microscreen.
3. Remove some of the microscreen units from operation (if you have more than one on line) to maintain design flows to units in service.

---

[7] ***Flow-equalization system.** A device or tank designed to hold back or store a portion of peak flows for release during low-flow periods.*

PROBLEM: HIGH SOLIDS LOADING

Problems caused by high solids loadings include:

1. Excessive head loss (above 12 inches or 30 centimeters) through the microscreen (be sure to check manufacturer's recommendations),
2. Excessive solids in the microscreen effluent,
3. Plugging of the microfabric with solids, and
4. Untreated water overflowing the microscreen bypass weir.

SUGGESTED CORRECTIVE ACTION

Use same action as suggested to solve problems created by high flows.

PROBLEM: HIGH OR LOW pH LEVELS

Problems caused by high or low pH levels include:

1. A high pH may result in the buildup of mineral deposits that will plug the holes on the microfabric.
2. A rapid change in pH may upset upstream treatment processes, thus increasing the suspended solids loadings applied to the microscreen.
3. A low pH may result in the corrosion of metal, especially the microfabric.

SUGGESTED CORRECTIVE ACTION

1. If rapid pH changes are occurring, monitor the plant influent and chemically adjust the pH as necessary to maintain the pH within desired levels. Attempt to correct the cause of the pH changes at the source.
2. Adjust the pH chemically to a balanced relationship with the alkalinity and temperature to prevent corrosion or scaling (use of Langelier Saturation Index)[8].
3. Divert abnormal pH flows into a flow-equalization system and return these flows slowly by intermixing them with the normal flows.
4. Remove mineral scaling from the microfabric with a mild acid wash.

PROBLEM: HIGH CONCENTRATIONS OF OIL AND GREASE

Problems caused by high concentrations of oil and grease include:

1. Plugging of the microfabric;
2. When the microfabric is plugged, there will be a high head loss through the unit, reduced flow through, and ineffective cleaning of the fabric by the water sprays.
3. Untreated water may overflow the microscreen bypass weir.

SUGGESTED CORRECTIVE ACTION

1. Reduce oil and grease loadings at the source.
2. Improve effectiveness of oil and grease removal equipment.
3. Add chemicals to improve oil and grease removals.
4. Increase the drum rotation speed.
5. Increase the water spray pressure.
6. Place additional microscreens in service.
7. Clean the microfabric with hot water, steam or chemicals.

4.213 Operational Strategy

The development of an operational strategy for a microscreening process treating wastewater will aid in dealing with situations such as sudden changes in applied water, training new operators or planning for the future. This section lists items for you to consider when developing your own operational strategy.

1. Maintain the filtering rates within the design limits.
2. Adjust the drum rotational speed as needed to compensate for extreme flow or suspended solids loadings.
3. Monitor and log head loss and flow rates daily because of an increasing head loss may indicate incomplete cleaning of the microfabric by the water spray system.
4. If the applied suspended solids load is increasing greatly due to poor settling in an upstream process, add chemicals to improve settling.
5. Be prepared to clean the microfabric manually if plugging occurs.
6. To increase the life of the microfabric, do not apply chlorine to the wastewater being treated at a location upstream from the microscreen.

4.214 Shutdown of Microscreen

The microscreen should not be left standing in dirty water. If the unit is to be left out of service for a week or longer, the tank should be drained and the microfabric cleaned. This will prevent clogging from solids drying on the fabric and also prevent slimes from growing in the portion underwater.

When a unit is shut down, complete these steps:

1. Shut off the applied water flow.
2. Allow the water to filter out of the drum.
3. Drain the microscreen structure.
4. Clean the fabric with water sprays.
5. Hose down the sump.
6. Hose down the trough.
7. Shut off the water sprays.
8. Shut off the drive unit.
9. Shut off the ultraviolet lights.

When treating wastewaters of typical strength and pH, corrosion usually is not a serious problem. If chlorine has been applied to the wastewater, corrosion can be a problem.

4.215 Troubleshooting

PROBLEM: POOR SUSPENDED SOLIDS REMOVAL

1. Check the hydraulic load. Performance is better at lower hydraulic loads. How does the flow compare with design flow?
2. Inspect the upstream units. Increased suspended solids loading to the microscreen will result in increased effluent suspended solids.

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[8] *If you wish to use this method, consult a textbook on sanitary engineering or water treatment.*

3. Determine the drum speed. At lower drum speeds a thicker mat of solids can build up and provide better straining.
4. Look for excessive turbulence upstream. Breaking up of the flocculated particles at the microscreen influent will result in poorer suspended solids removal.
5. Check for pin floc carry-over from the upstream secondary clarifiers. Pin floc will result in a poor quality effluent even if the microscreen is operating properly because of the difficulty of removing pin floc.

PROBLEM: HIGH HEAD LOSS THROUGH MICROSCREEN

1. Determine the drum rotation speed. If drum is rotating too slowly, the mat will become too thick and produce a high head loss.
2. Inspect the upstream units. Increased suspended solids loadings will result in a rapid buildup of the solids mat.
3. Examine the water spray system for clogging of nozzles.
4. Determine the pressure in the water spray system. A higher pressure may be needed.
5. Look for a buildup of iron, manganese or grease on the microfabric. The fabric may need a special cleaning with acid, steam or hot water.

PROBLEM: POOR SOLIDS REMOVAL AND LACK OF HEAD LOSS

1. Look for damaged or torn microfabric.
2. Inspect for improperly installed microfabric panel.
3. Check for damaged end seal on the drum.
4. Look for plugged or inoperative head loss indicator.

4.22 Maintenance of Microscreen

As with all equipment, the operator must read the manufacturer's recommendations and follow them as they pertain to each installation. The following maintenance points should be considered:

1. Lubricate bearings, chains, and drive units as recommended.
2. Wash down daily and maintain good housekeeping practices.
3. Dewater sump monthly (or as needed) and remove solids and debris.
4. Inspect microfabric condition monthly.
5. Clean algae and slime growth with chlorox or bactericidal soap.
6. Clean grease and oil from microfabric with hot water or steam. *CAUTION.* Do not clean *PLASTIC* microfabric with steam. Use only hot water (120°F or 49°C) to remove grease. Steam may damage plastic microfabric.

4.23 Safety

Always think safety when working around mechanical equipment. Lock out and tag the drive units before working on the motor, the drive units, the drum or any electrical system.

When cleaning with an acid wash or a chlorine solution, wear protective clothing. This includes rubber aprons, rubber gloves and boots, and face shield and eye goggles if splashing of the chemical may occur.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 332.

4.2G What kinds of abnormal conditions could you encounter when operating a microscreen?

4.2H What problems are caused by high or low pH levels when operating a microscreen?

END OF LESSON 2 OF 4 LESSONS
ON
SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 4 Lessons)

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

9. How do microscreens remove particles smaller than the actual openings of the fabric?
10. What is the impact of microscreens on the solids handling facilities of a treatment plant?
11. Why is a pre-start inspection important before starting any major piece of equipment?
12. What operational action would you consider taking if a microscreen had to handle higher-than-design flows and solids loading?

CHAPTER 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

(Lesson 3 of 4 Lessons)

4.3 SOLIDS REMOVAL FROM SECONDARY EFFLUENTS USING GRAVITY FILTERS

4.30 Gravity Filters

4.300 Use of Filters

Gravity filtration is second only to gravity sedimentation for the separation of wastewater solids. This same process, using deep-bed filtration and granular media, has long been used in municipal and industrial water supplies. However, these systems are more frequently used for domestic water supplies that have much lower suspended solids concentrations than found in the effluent from secondary wastewater treatment plants.

4.301 Description of Filters

Applied water generally flows through wastewater filters from top to bottom. The applied water is distributed evenly over the surface of the filter media thru an inlet distribution system. This may be the same system as that used to uniformly collect the dirty backwash water.

The water travels through the filter media where the solids are trapped. The filter bed may be made up of one or several materials and/or several grades of materials. This is determined by the designer based primarily upon the quality of the applied water.

The underdrain system is designed to collect the filtered water uniformly throughout the bed. It also is used to uniformly apply the backwash water during backwashing. The system design must prevent the filter media from passing into the underdrain system, thereby being lost from the bed.

A surface wash system is beneficial during backwashing to scrub the surface mat, thus breaking it up with minimum amounts of water. In some installations air is used in place of surface washing as a means of breaking up the accumulated solids.

Valves control the volume, direction and duration of flows through the unit.

Instruments are used to monitor and record the volumes and quality of the water being processed through the filtering system.

4.302 Filtering Process

Water to be treated enters at the top of the filter bed through an inlet valve and is distributed over the entire filter surface. The water passes evenly down through the media (sand) and leaves the solids behind. Filtered water then travels out the bottom of the filter and into the underdrain collection system which is designed to uniformly collect the flow. Once inside the underdrain collection system, the water passes through a flow meter and rate-control valve. The rate-control valve maintains the desired flow through the filter and prevents backwash water from entering the filtered water during backwashing.

Most filters operate on a batch basis whereby the filter operates continuously until its capacity to remove solids is reached. At this time it is completely removed from service and cleaned. Other designs are available that filter continuously with a portion of the media always undergoing cleaning. The cleaning of the media may take place either externally or in place.

4.303 Backwashing Process

As suspended solids are removed from water, the filter media becomes clogged. This is indicated by a head loss reading. Through operating experience, the maximum head loss before backwashing will be determined. The filter should be backwashed after the solids capacity of the media has been met, but before solids break through into the effluent.

Backwashing consists of closing valves to stop influent flow and to protect the filtered water. Backwash water either flows by gravity or is pumped to the filter. This water flows through the underdrain system and back through the media. As the water flows through the media, the sand particles are lifted and are cleaned by rubbing against each other. The solids retained by the media are washed away with the backwash water and the media has been cleaned.

If the media is cleaned externally, the media is removed from the filter bed, cleaned in a separate system and recycled back into the bed. In-place cleaning involves washing a small section of the filter bed with a traveling backwash water or air-pulsing system while the remainder of the bed remains in service.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3A When should a gravity filter be cleaned?

4.3B Do most filters operate on a batch or on a continuous basis?

4.31 Methods of Filtration

4.310 Filter Types

Most filters used in wastewater treatment are "rapid sand" filters (Figure 4.16). They also may be called "downflow" (water flows down through the bed) or "static bed" (bed does not move or expand when filtering). These filters operate continuously until they must be shut down for backwashing. Other designs, such as the upflow and the biflow, are on the market. Both of these designs are attempts to use more of the filter media, thereby removing and holding more solids per filter run.

In the upflow filter (Figure 4.17), water enters the bottom and is removed from the top. The biflow system has water applied at both the top and bottom and water is withdrawn from the interior of the bed. Filters are always backwashed in an upflow direction regardless of the operating flow direction.

4.311 Surface Straining

Downflow filters are designed to remove suspended solids by either the surface-straining method or the depth-filtration method. In surface straining the filter is designed to remove the solids at the very top of the media. The fine grade-sized media is uniform throughout the bed. Because of this conformity, surface-straining systems will have a rapid head loss buildup, short filter runs, and they must be backwashed frequently. There are, however, no problems with breakthrough of solids. The solids compress into a mat at the surface which aids in removing solids; however, the mat is difficult to remove during backwashing. Backwashing, although needed more frequently, requires less water per wash than does a depth-filtration system.

4.312 Depth Filtration

Depth filtration is designed to permit the solids to penetrate deep into the media, thereby capturing the solids within as well as on the surface of the media. Depth filtration will have a slower buildup of head loss, but solids will break through more readily than with surface straining.

To reduce breakthrough, yet retain depth filtering, the multi-media design is used. This combines a fine, denser media (sand) on the bottom with a coarse, lighter media (anthracite coal) on the top (Figure 4.18). The coarse media remove large solids that would quickly clog finer media. The fine media will surface-strain solids that penetrate the full depth of the coarse media bed thereby preventing a breakthrough of solids. The filter is designed to prevent the fine media from escaping unless the head loss becomes too great.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3C What is meant by the following terms that are used to describe "rapid sand" filters?

1. Downflow
2. Static bed

4.3D From what part of the filter are solids removed by

1. Surface straining?
2. Depth filtration?

4.32 Location of Filters in a Treatment System

In wastewater treatment, the filters may be used in the following modes (Figure 4.19):

1. To polish secondary effluent without the addition of chemicals as filter aids just ahead of the filters,
2. To polish secondary effluent with the addition of chemicals as filter aids just ahead of the filters,
3. To polish secondary effluent that has been chemically pretreated and settled, and
4. To polish raw wastewater that has undergone coagulation, flocculation and sedimentation in a physical-chemical treatment system.

4.33 Major Parts of a Filtering System (Figure 4.20)

This section describes the major parts of a filtering system and also how each part works or functions during the filtration process.

4.330 Inlet

The filter inlet gate allows the applied water to enter the top of the filter media. When closed it will permit emptying the filter for backwashing or maintenance.

4.331 Filter Media

The filter media selection is one of the most important design considerations. Filter beds are made up of silica sand, anthracite coal, garnet or ilmenite. Garnet and ilmenite are commonly used in multi-media beds.

Because of rapid plugging, the conventional single-media filter bed commonly used in potable water systems is generally unsatisfactory in removing solids from wastewater.

To lengthen filter runs and use the full bed depth, the dual- and multi-media filters are used. A layer of coarse media (anthracite) is placed over finer, dense material (sand or garnet). The coarse layer allows deep penetration of the solids into the bed causing a minimum of head loss. The fine material prevents breakthrough of solids into the effluent.

4.332 Filter Underdrains (Figure 4.21)

The filter underdrain system is designed to contain the filter media within the bed and to maintain uniform water flows through the entire bed during both filtering and backwashing.

4.333 Filter Media Scouring

If the filter media is not cleaned thoroughly at each backwashing, a buildup of solids will occur. The end result of incomplete cleaning is the formation of "mud balls" within the bed. These mud balls settle to the filter bottom and in time require rebuilding the entire bed. "Surface wash" and "air scour" are two systems used to improve cleaning of the media.

The surface wash system consists of either fixed or rotating nozzles installed just above the media. During a backwash, the bed expansion places the nozzles within the media where high-pressure water jetting out of the nozzles will agitate and clean the surface. Because these wash systems are designed primarily to break up the surface mat, deep filtering beds need nozzles placed deeper within the media.

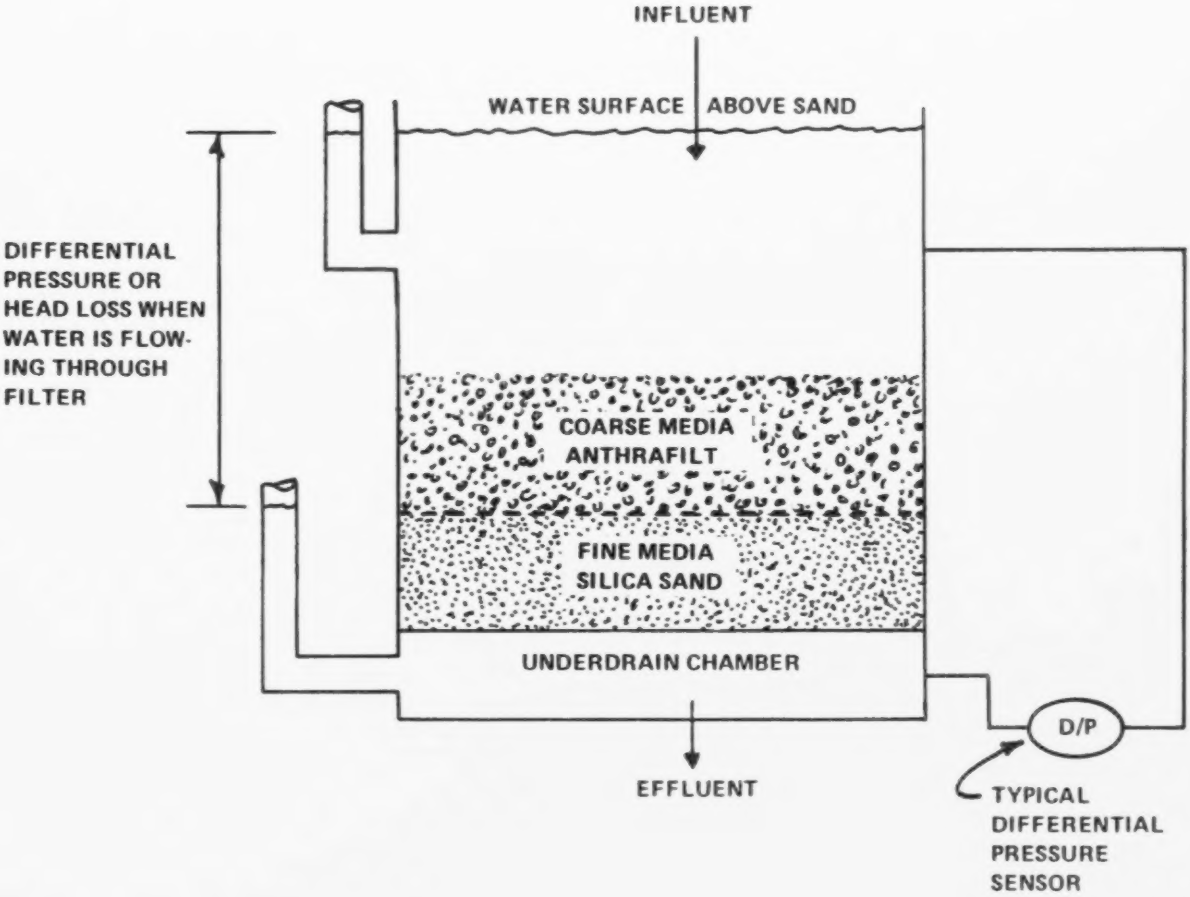

INFLUENT
WATER SURFACE ABOVE SAND
DIFFERENTIAL PRESSURE OR HEAD LOSS WHEN WATER IS FLOWING THROUGH FILTER
COARSE MEDIA ANTHRAFILT
FINE MEDIA SILICA SAND
UNDERDRAIN CHAMBER
EFFLUENT
D/P
TYPICAL DIFFERENTIAL PRESSURE SENSOR

Fig. 4.16 Differential pressure through a sand filter

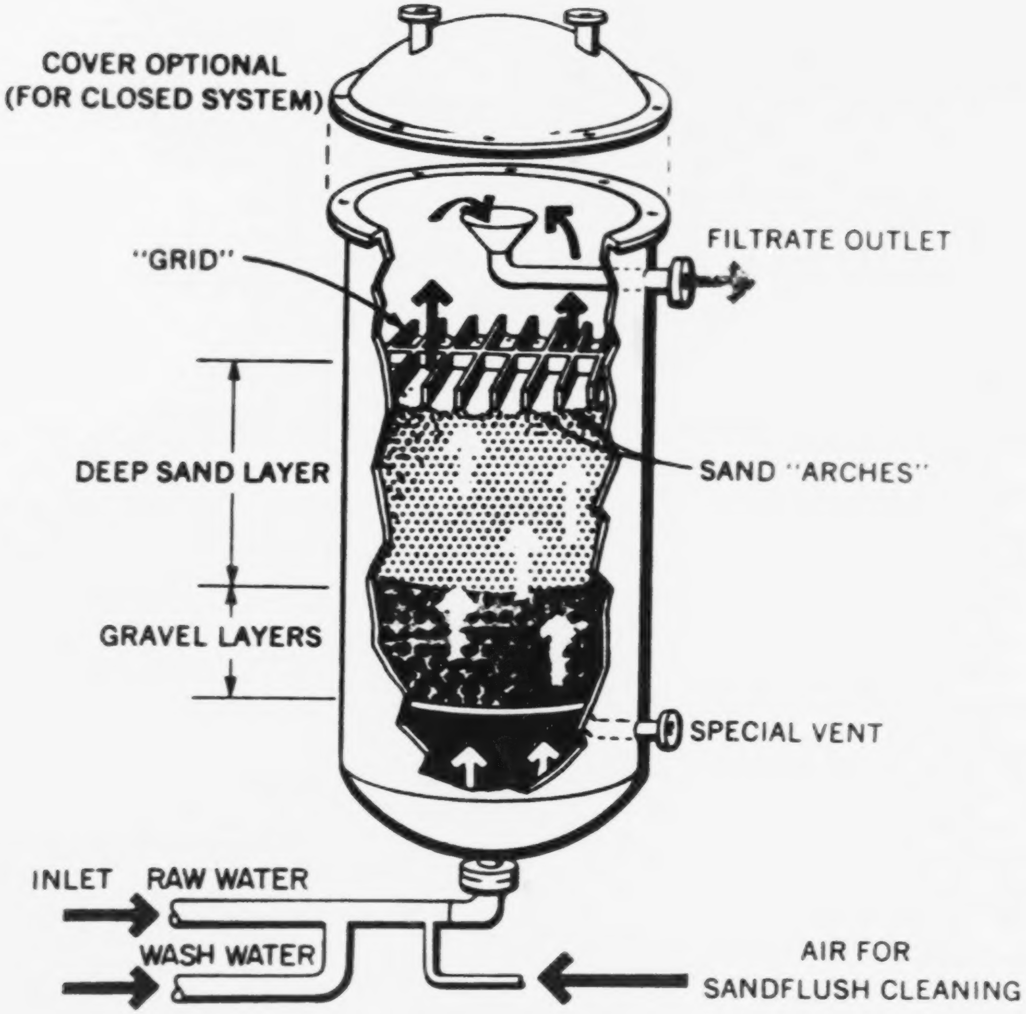
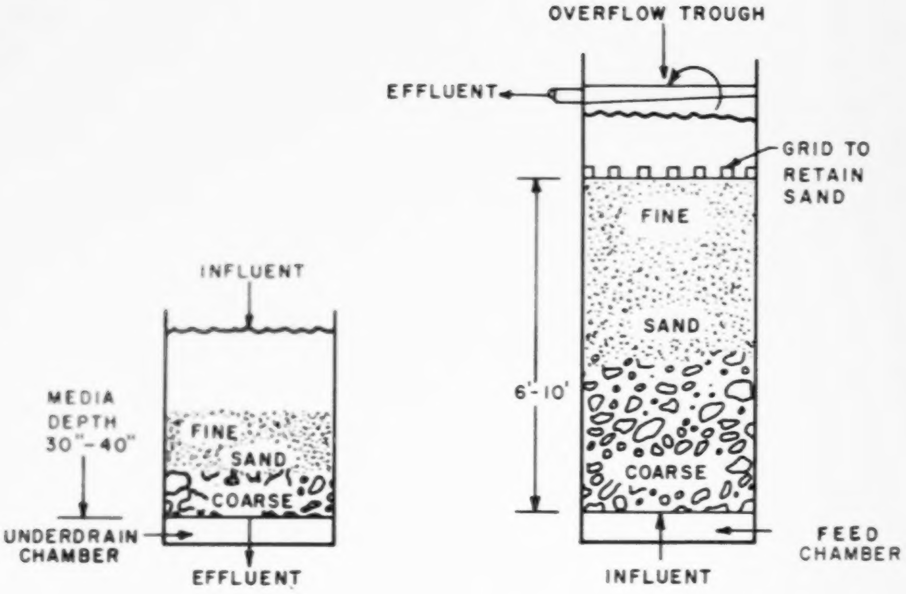

COVER OPTIONAL
(FOR CLOSED SYSTEM)
"GRID"
FILTRATE OUTLET
DEEP SAND LAYER
SAND "ARCHES"
GRAVEL LAYERS
SPECIAL VENT
INLET
RAW WATER
WASH WATER
AIR FOR
SANDFLUSH CLEANING

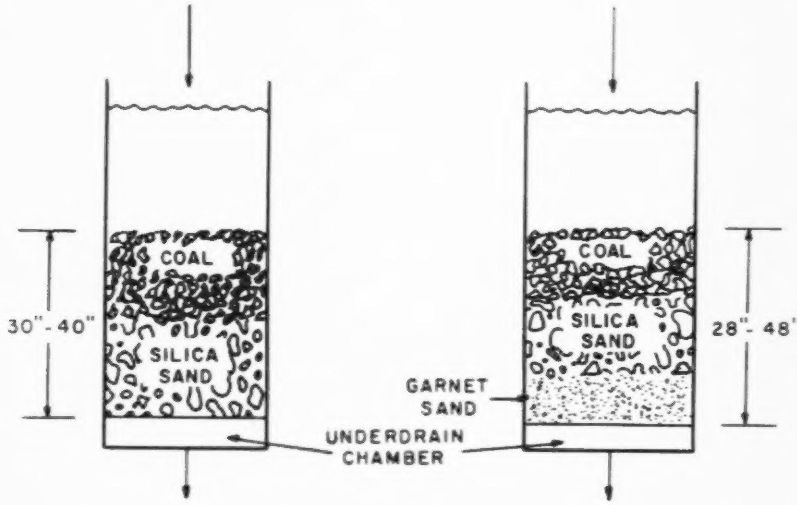
Fig. 4.17 Cross section of upflow filter

(Source: EPA Process Design Manual for Suspended Solids Removal)


OVERFLOW TROUGH
EFFLUENT
GRID TO RETAIN SAND
FINE
SAND
6'-10'
COARSE
FEED CHAMBER
INFLUENT
INFLUENT
MEDIA DEPTH 30"-40"
FINE
SAND
COARSE
UNDERDRAIN CHAMBER
EFFLUENT

(a) CONVENTIONAL DOWNFLOW FILTER

(b) UPFLOW FILTER


30"-40"
COAL
SILICA SAND
COAL
SILICA SAND
28"-48"
GARNET SAND
UNDERDRAIN CHAMBER

(c) DUAL-MEDIA DOWNFLOW FILTER

(d) MULTI-MEDIA DOWNFLOW FILTER

Fig. 4.18 Filter configurations

(Source: EPA Process Design Manual for Suspended Solids Removal)

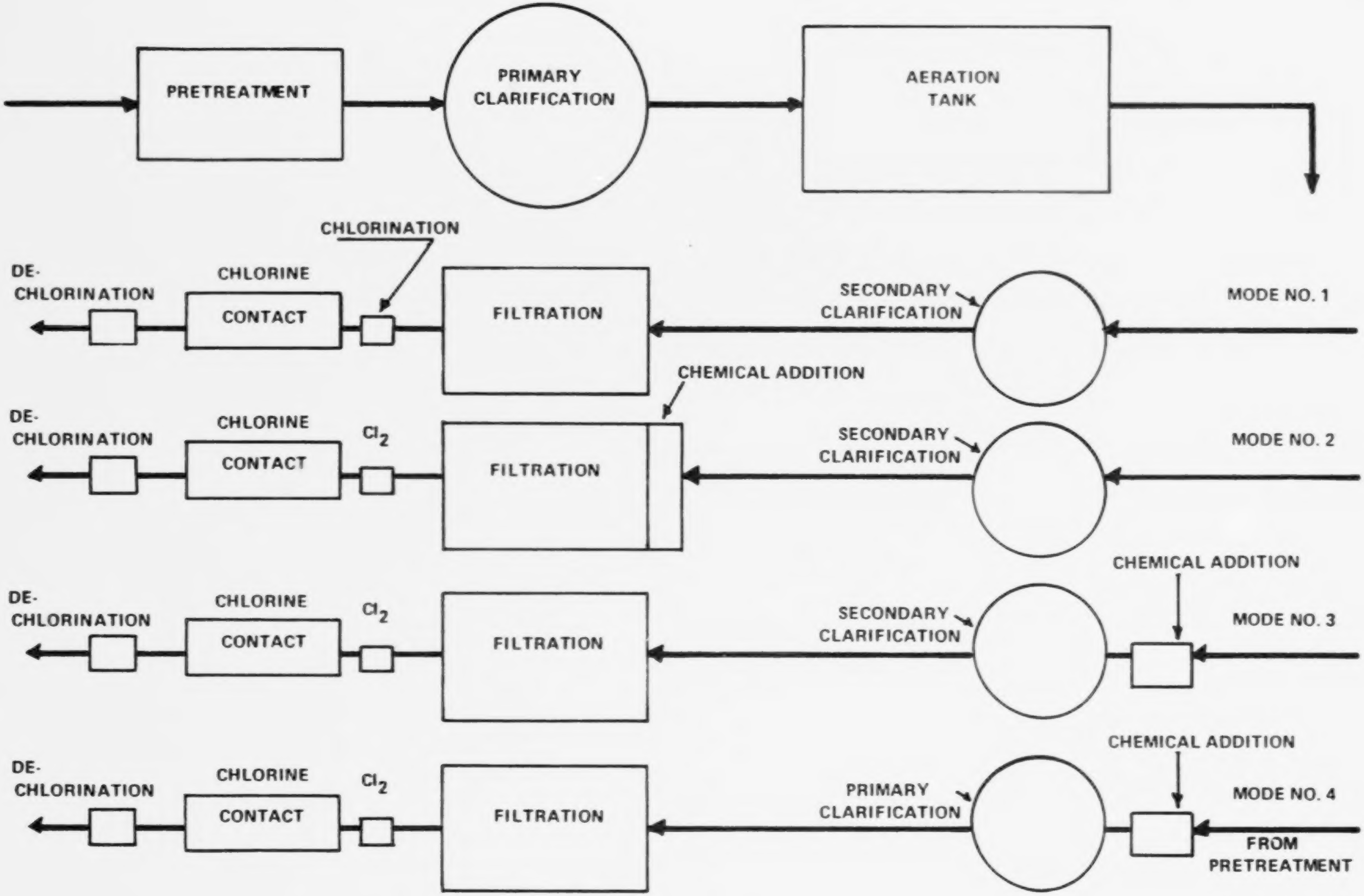

PRETREATMENT
PRIMARY CLARIFICATION
AERATION TANK
CHLORINATION
DE-CHLORINATION
CHLORINE CONTACT
FILTRATION
SECONDARY CLARIFICATION
MODE NO. 1
CHEMICAL ADDITION
DE-CHLORINATION
CHLORINE CONTACT
Cl2
FILTRATION
SECONDARY CLARIFICATION
MODE NO. 2
CHEMICAL ADDITION
DE-CHLORINATION
CHLORINE CONTACT
Cl2
FILTRATION
SECONDARY CLARIFICATION
MODE NO. 3
CHEMICAL ADDITION
DE-CHLORINATION
CHLORINE CONTACT
Cl2
FILTRATION
PRIMARY CLARIFICATION
MODE NO. 4
FROM PRETREATMENT

Fig. 4.19 Four possible modes of using filters to remove solids

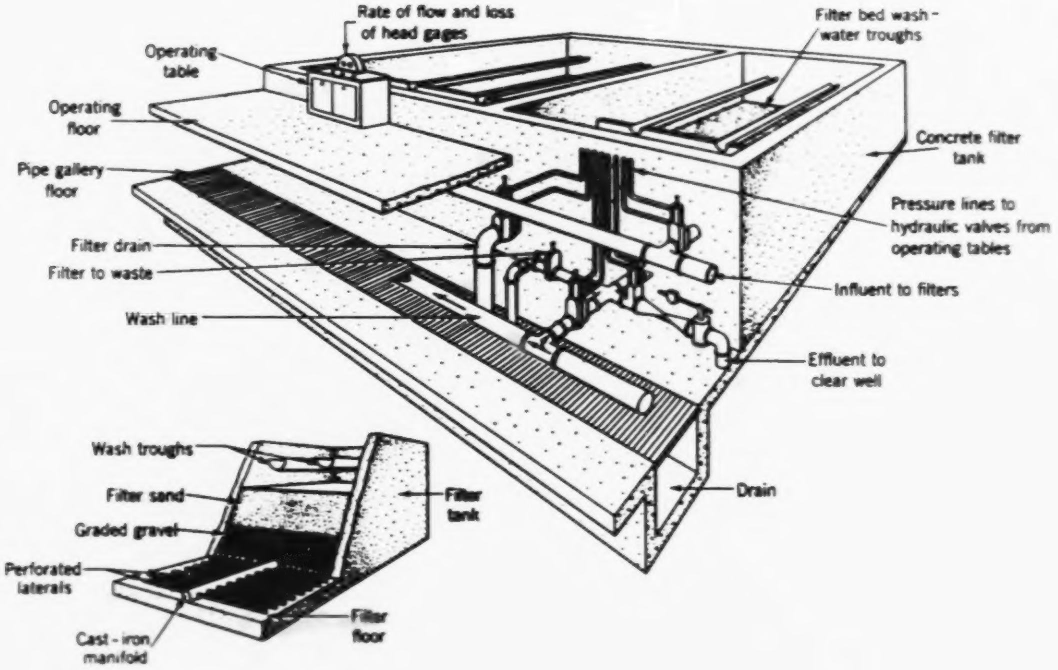
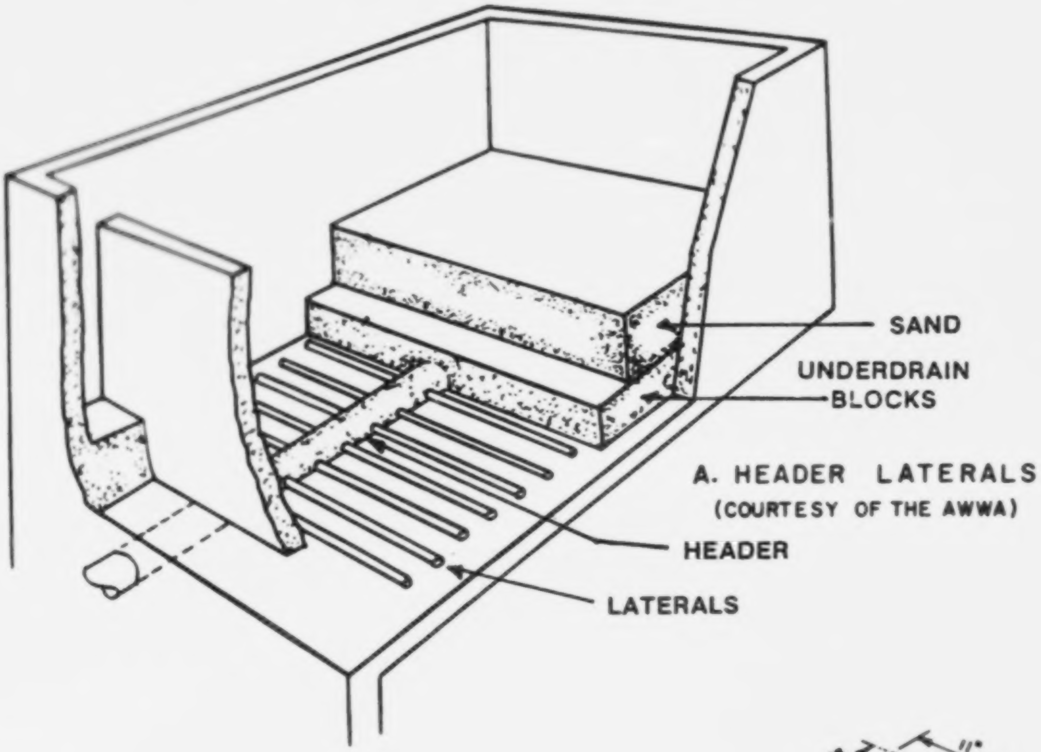

Rate of flow and loss of head gages
Filter bed wash-water troughs
Operating table
Operating floor
Concrete filter tank
Pipe gallery floor
Pressure lines to hydraulic valves from operating tables
Filter drain
Filter to waste
Influent to filters
Wash line
Effluent to clear well
Wash troughs
Filter sand
Filter tank
Drain
Graded gravel
Perforated laterals
Filter floor
Cast-iron manifold

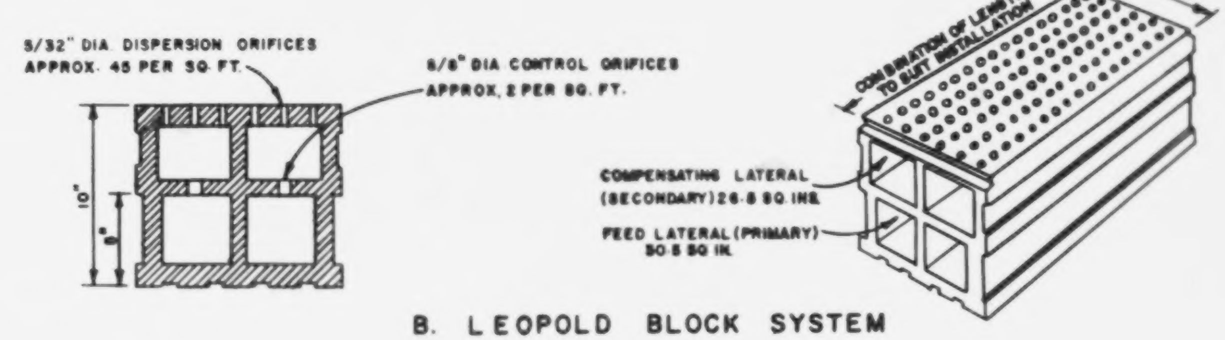
Fig. 4.20 Typical rapid sand filter

(From *WATER SUPPLY AND TREATMENT* by C.P. Hoover, permission of National Lime Association)


SAND
UNDERDRAIN BLOCKS
HEADER
LATERALS

A. HEADER LATERALS

(COURTESY OF THE AWWA)


5/32" DIA. DISPERSION ORIFICES APPROX. 45 PER SQ. FT.
5/8" DIA CONTROL ORIFICES APPROX. 2 PER SQ. FT.
10"
6"
COMBINATION OF LENGTHS TO SUIT INSTALLATION
11"
COMPENSATING LATERAL (SECONDARY) 26.8 SQ. INS.
FEED LATERAL (PRIMARY) 30.5 SQ IN.

B. LEOPOLD BLOCK SYSTEM

(Courtesy F. B. Leopold Co.)

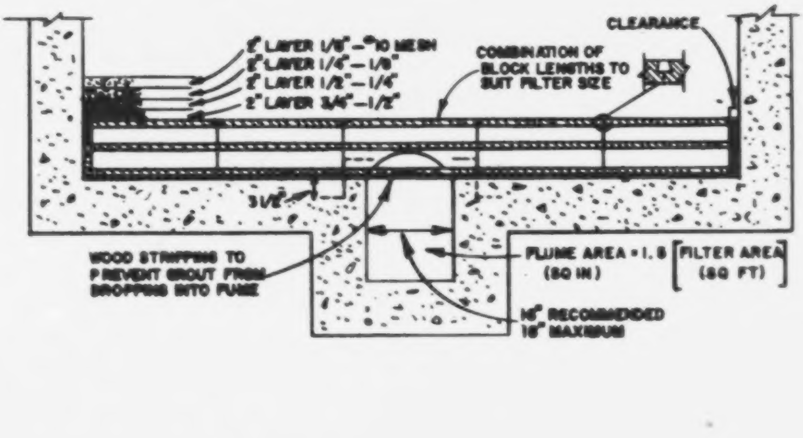

2" LAYER 1/8" — #10 MESH
2" LAYER 1/4" — 1/8"
2" LAYER 1/2" — 1/4"
2" LAYER 3/4" — 1/2"
COMBINATION OF BLOCK LENGTHS TO SUIT FILTER SIZE
CLEARANCE
3 1/2"
WOOD STRIPPING TO PREVENT GROUT FROM DROPPING INTO FLUME
FLUME AREA = 1.5 [FILTER AREA] (SQ IN) (SQ FT)
16" RECOMMENDED
18" MAXIMUM

Fig. 4.21 Underdrains

(Source: EPA PROCESS DESIGN MANUAL FOR SUSPENDED SOLIDS REMOVAL)

The air scour system injects air into the bottom of the bed. This agitates the entire bed, yet requires no additional washwater. Care must be taken to prevent air and water flowing at the same time, or the media will be washed out and lost.

4.334 Washwater Troughs

During backwashing, the accumulated solids strained out by the filter media are carried out of the filter bed via the backwash water troughs. The troughs must be level to uniformly collect and withdraw the backwash water. This will help prevent dead spots (short-circuiting) during the backwash operation.

A smooth trough surface, such as fiberglass, will reduce routine cleaning; however, fiberglass troughs may be damaged more easily by the weight of the backwash water than steel or concrete troughs. Filter troughs, particularly fiberglass, must be well anchored to assure that they will not warp or attempt to float during backwashing. They also must be designed to withstand the weight of water if filled when there is no water over the bed.

4.335 Backwash Water Drain

In a wastewater treatment plant, the filter drain allows the backwash water to leave the filter and return to the plant headworks for reprocessing. This drain must be opened before the backwash water flow begins, but not before the water is filtered down below the level of the backwash trough. If the drain opens while the filter is still full of applied water, the water above the troughs will needlessly be recycled back through the plant.

The drain should be closed completely before the inlet valve is opened or applied water again will be wasted.

4.336 Backwash Water Supply

The backwash water is usually water that has gone through the complete treatment process and is of the best quality available. If non-filtered water is supplied to the backwash system, clogging of the underdrain system may occur.

Filter backwashes require large volumes of water over a short period of time; therefore, small- to medium-size plants need a washwater storage reservoir. Water from the chlorine contact tank commonly is used.

Large filters are often split in half to reduce the size of pumps and piping required for backwashing. This also can reduce the water storage requirements because a pause between washing the two halves will provide time to refill the storage reservoir.

Sectional filters (Figure 4.22), designed to backwash one small section at a time, do not require a large backwash water storage supply. These filters used pumped water as it is being filtered through other sections.

4.337 Backwash Water Rate Control

The backwash water may be supplied through pumps or by gravity from a storage tank. Both methods require careful control of the flow rate.

Backwash water supplied through pumps will maintain a more constant flow over the entire wash cycle than washwater from gravity storage. Water supplied from storage tanks may require adjustment of the rate-control valve to maintain constant flows as the storage tank level drops, due to a decrease in the available pressure head on the backwash water.

4.338 Used Backwash Water Holding Tank

The filter backwash water contains solids concentrated from many gallons of applied water. Because of the high solids concentration, this water must be retreated in the treatment process. Since the backwash flow rates are very high, they must be dampened through a holding tank to avoid hydraulic overloads on the treatment plant. If these high flows are returned directly to the headworks in all except the very large plants a hydraulic overload will occur which will upset the treatment process and flow pacing system. A filter system designed to backwash like the sectional filter may avoid the need for a used backwash water holding tank. A holding tank is generally provided to prevent plant overloads. The tank is filled during the backwash operation and slowly emptied into the plant headworks between washings. Some improvement in primary settlement may be noted because of this recycled water.

4.339 Effluent Rate-Control Valve

A valve automatically controls the filtered water flow leaving the bed. The effluent rate-control valve is designed to maintain a constant water level in the filter. When operating a clean filter, this valve will be closed down restricting the flow. As the head loss through the media increases, this valve must open more to maintain a constant flow. This valve must be closed during filter backwash to prevent backwash water from mixing with previously filtered water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3E What kind of material is used for filter media?

4.3F What can happen if the filter media is not thoroughly cleaned during each backwashing?

4.3G Why should the backwash water be of the best quality available?

4.3H What is the purpose of a used backwash water holding tank?

4.34 Filter System Instrumentation

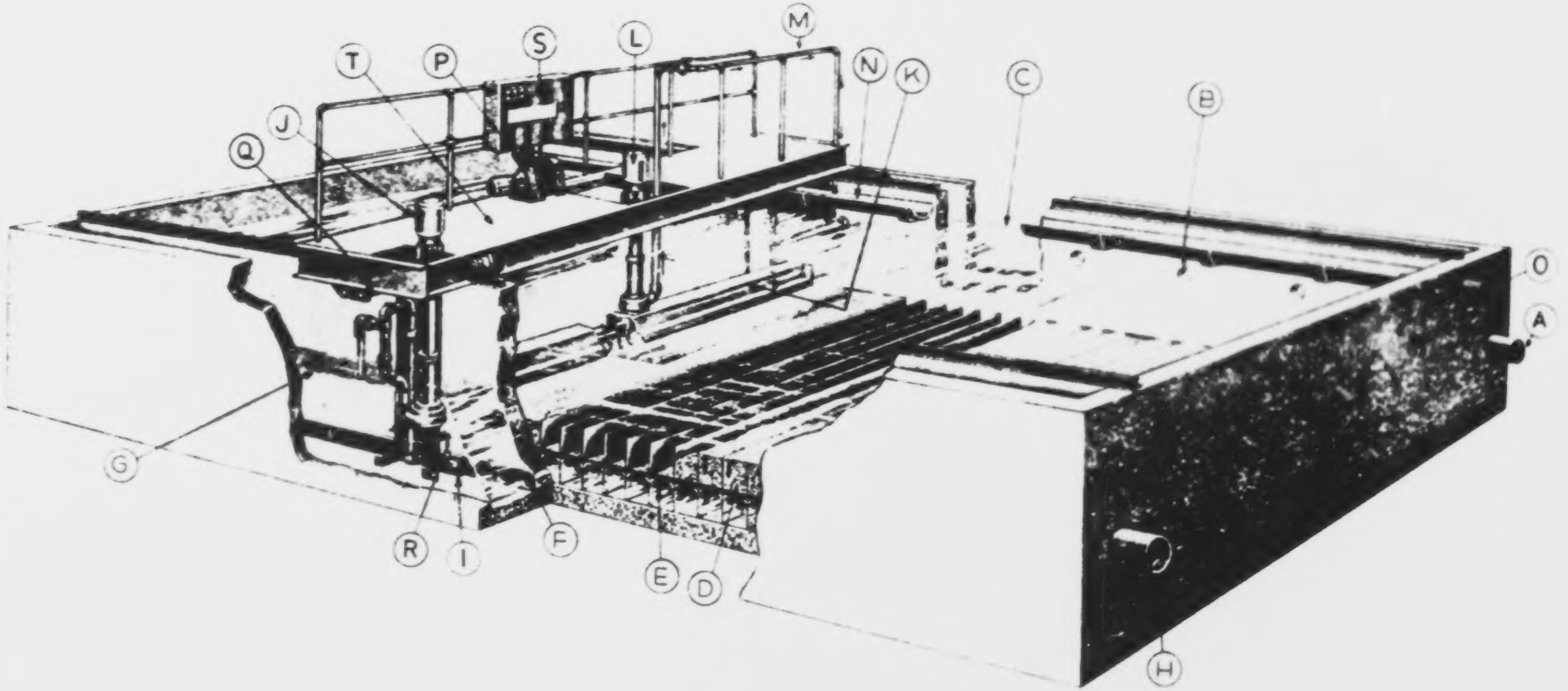
Instrumentation is essential for all but the small package plant installations. Instrumentation associated with filtering is used to monitor the plant performance, to operate the plant in the absence of the operator and to trigger an alarm if abnormal conditions develop. The system may be simple or very complex and, depending on the facilities, each has its place.

Instrumentation, just as all equipment, is only as useful as allowed by the quality of maintenance. Stated another way, if there are intermittent errors in a flow-meter signal and they are not corrected, then the operator cannot trust any of the readings and must disregard all of them. The usefulness of the instrument is then very limited.

Comments regarding instrumentation in the following sections are applicable to plants of all sizes.

4.340 Head Loss

Head loss is one of the most important control guidelines in the operation of the rapid-sand filter. Each filter or filter half requires a head loss indicator, preferably one with a read-out chart. This will indicate the present condition of the bed, its ability to remove solids, and the effectiveness of the backwash operation.



A Influent line
B Influent ports
C Influent channel
D Compartmented filter bed
E Sectionalized under drain

F Effluent and backwash ports
G Effluent channel
H Effluent discharge line
I Backwash valve
J Backwash pump assembly

K Washwater hood
L Washwater pump assembly
M Washwater discharge pipe
N Washwater trough
O Washwater discharge

P Mechanism drive motor
Q Backwash support retaining springs
R Pressure control springs
S Control instrumentation
T Traveling backwash mechanism

Fig. 4.22 Sectional filter

(Permission of Environmental Elements Corporation)

Head loss is determined by measuring the water pressure above and below the filter media (see Figure 4.16, page 302). With the filter out of service, the pressure will be the same (zero difference).

When water flows through the bed, the pressure below the media will be less than the pressure above the media (when the pressure levels are measured or read at the same elevation). Measured in feet (or meters) of water, the difference becomes the head loss.

As the media bed becomes filled with solids, the head loss becomes greater. There is a point at which little or no water can pass through the filter. The operator wants the head loss to always be less than at that point; therefore, the filter backwash control point must be less than the maximum design head loss.

A typical set point to start backwash is at 7.0 feet (2.0 m) of head loss. If a filter is operating with a 6.0-foot (1.8 m) head loss, the operator knows the filter will need washing soon. If after washing the head loss is 4.0 feet (1.2 m), this indicates a very poor washing or it may indicate a malfunctioning instrument. After a proper washing, the head loss should be less than 0.5 feet (0.15 m) at start-up. The head loss will then slowly increase to the point where backwashing is required again.

4.341 Filter Flow-Rate and Totalizer

Each filter or filter half requires a flow indicator and totalizer on the filtered water line. This is needed to determine proper filtering rates (gal/min/sq ft or liters/sec/sq meter). Also, with the total volume filtered and the volume of backwash water used, the percent of production (filtered) water used for backwashing can be calculated. This is important because excessive wash water usage is costly and must be controlled. The backwash water should average 5 to 10 percent of total water production.

4.342 Applied Turbidity

A continuous-reading turbidimeter with read-out chart on the applied water is useful in monitoring the performance of the secondary settling tanks. This read-out will alert the operator to pending problems if the turbidity suddenly increases. With experience, chemical dosages can be adjusted as turbidity changes.

4.343 Effluent Turbidity

A continuous reading of turbidity with a chart on the filter effluent will monitor the filter performance. A sudden increase may indicate a filter breakthrough (cracked bed) and may be used or instrumented to set off alarms if specified limits are exceeded. One turbidimeter unit, with proper valving, may be used to monitor more than one filter.

4.344 Indicator Lights

Indicator lights are beneficial to operators in keeping track of the filter system. Lights can easily indicate which filter is in service, out of service, or backwashing. They can indicate if filter pumps, wash water pumps or air blowers are running, out of service or on standby and ready to run. Indicator lights can be used with the alarm system to show abnormal conditions.

4.345 Alarms

Alarms needed to alert the operator should include high applied water level, high turbidity and pump malfunctions. Backwash water supply and holding tanks both need high water level alarms.

All alarms should be tested for proper functioning at least every 60 days.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3I How is the head loss through the filter media determined?

4.3J How often should filter system alarms be tested for proper operation?

4.35 Operation of Gravity Filters

4.350 Pre-Start Checklist

Before starting up any major system, such as gravity filters, a thorough check of each component must be made to prevent damage to the equipment and/or injury to personnel. The following items should be included in your checklist for starting filtering systems.

1. Be sure all construction debris has been removed. Wood scraps, concrete chips, nails and other trash can damage equipment such as pumps and valve seats. Trash dropped into the filter media will work its way to the bottom, thus reducing the effective area of the filter.
2. Inspect the electrical installation for completeness. Check safety lockouts, safety covers and equipment overload protections.
3. Check motors and drives for proper alignment, for proper safety guards, and for free rotation.
4. Examine motors, drive units and bearings for proper lubrication.
5. Check motors for proper rotation. (A three-phase motor may run in either direction.)
6. Inspect pumps and motors for excessive vibration.
7. Fill tanks and piping and look for leaks.
8. Open and close valves manually and run each valve through a complete cycle to check limit setting.
9. Put the automatic controls through a "dry run."
10. Inspect the total system for safety hazards.
11. Backwash the media several times. Skim the fines from the surface between each washing prior to placing filter into service.

4.351 Normal Operation

Since most wastewater gravity filters are deep-bed, downflow, rapid-sand type filters, this section will present information based on them. Nevertheless, most of the information can be applied to other filter designs with some possible modifications.

FILTERING

The applied water enters at the top of the filter bed through an inlet valve and is distributed over the entire filter surface. The water passes evenly down through the media and leaves the solids behind. Filtered water then travels out the bottom of the filter and into the underdrain collection system which is designed to uniformly collect the flow. Once inside the underdrain collection system, the water passes through a flow meter and rate-control valve. The rate-control valve maintains the desired flow through the filter and prevents backwash water from entering the filtered water during backwashing. Successful filter operation depends on effective backwashing of the filter media.

BACKWASHING

As suspended solids are removed from water, the filter media becomes clogged. This is indicated by the head loss reading (Figure 4.16, page 302). Through operating experience, the maximum head loss before backwashing will be determined. The filter should be backwashed after the solids capacity of the media has been met, but before solids break through into the effluent.

By maintaining complete records, the operator can monitor the filter efficiency and determine if the backwashings are adequate.

Backwashing a filter manually, although sometimes necessary, is very time-consuming; moreover, manual backwashings are inconsistent. Automatic backwashing, on the other hand, can be a simple procedure which requires a minimum of operator time.

To maintain smooth operations, the automatic backwash cycle should be initiated by the operator. This mode of operation permits the operator to backwash at a convenient time thereby allowing time for keeping records current and completing the necessary maintenance duties. Automatically starting backwashes, although workable in a large system, can be very inconvenient to the operation of a small system.

At the start of the backwash cycle, the rate-control valve must be opened slowly to a low-rate of backwash. This prevents damaging the underdrain system or disturbing the rock and gravel layers of the bed. This damage can occur when an empty bed has high backwash water flows suddenly injected into it or if trapped air in the piping and underdrain system is violently forced into the bed. After the air has been purged and the water level is up to the washwater troughs, the bed can no longer be damaged by high backwash rates.

Some plants use an air scouring system to clean the filter media. The air scour system injects air into the bottom of the media bed. This agitates the entire bed, yet requires no additional washwater. Care must be taken to prevent air and water flowing at the same time, or the media will be washed out and lost.

To prevent the loss of filter media into the backwash troughs:

1. Draw the water-level in the filter down to witnin a few inches over the top of the filter media,
2. Pause a moment after air washing before starting the water wash,
3. Wash with a low water-flow rate until the trapped air has escaped the filter media, and
4. Never backwash a filter with water containing large quantities of air.

The media becomes intermixed during the high agitation of air scrubbing or high-rate backwashing. With proper control, however, the media will automatically regrade due to the difference in specific gravities of the particles.

By design, the filter media is prevented from escaping into the underdrain system; nevertheless, operational care must be taken to prevent damaging the underdrains while backwashing or the filter media will be lost into the underdrain collection system.

Uniform water flow through the filter bed is important to prevent the breakthrough of solids in the effluent due to localized high velocities. Also, high velocities will cause the media to be disturbed and relocated if the backwash flow is not uniform throughout the bed.

The following situations indicate a disturbed or damaged filter underdrain:

1. Consistently poor quality effluent (high suspended solids levels) while there is little buildup of the filter head loss.
2. Boiling areas and very quiet ("dead") areas of the filter media during backwashing. This is most noticeable during high wash rates in a nearly clean filter.
3. Filter media in the effluent.

Improper control of the system during backwashing is generally the cause of damaged filter bottoms, providing they were properly installed. Damage to the filter bottom could result if:

1. The maximum backwash rate is allowed to enter into an empty filter, or
2. A large volume of air preceded the maximum backwash rate causing a *WATER HAMMER.*[9]

The only way to correct a damaged filter bottom is to remove the media and rebuild the bed. A bed with the media displaced to a minor extent may be corrected by extended and properly controlled backwashing. This will regrade the media.

After backwashing, the filter normally has water up to the sides of the troughs. To fill the remaining portion of the filter, open the inlet valve. If the filter has been drained for maintenance, fill the filter, as if you were starting to backwash, up to the top of the sides of the troughs. Now you can fill the filter using the inlet valve. Be sure to waste some of the filtered water at the start until completely filtered and clear water is leaving the filter. An empty filter should not be filled through the inlet valve because the water falling onto the media will disturb the bed and result in uneven filtering. Also, filling the backwash troughs with water in an empty filter will place an unnecessary load (weight of water) on the troughs.

After the filter media is clean, the backwash water flow is slowly reduced. This permits the media to regrade itself through gravity settling. The heavier particles (gravel, garnet, sand) will settle to the bottom first and as the uplift velocities reduce, the lighter particles (anthracite coal) will settle, thereby regrading the filter bed back to its original placement. This regrading must occur at the end of each backwash cycle.

When the used backwash water holding tank is empty, the tank should be inspected. A check observation of the solids settled on the bottom of the empty holding tank will alert the operator to any loss of filter media due to improper backwash procedures, such as excessively high flow rate or short-circuiting.

By analyzing the records and observing the complete wash cycle, the operator can determine if the backwashing sequence is adequate. If highly turbid water is still in the bed at the end of the cycle, experiment with one or all of the following:

1. Adjust the media scouring time,
2. Adjust the low wash rate,
3. Adjust the high wash rate,
4. Adjust the time of regrading the media, and/or
5. Backwash more frequently by beginning to wash at a lower head loss.

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[9] *Water Hammer. The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3K Why should a pre-start check be conducted before starting filtering systems?

4.3L What is the purpose of the rate-control valve?

4.3M When should a filter be backwashed?

4.352 Abnormal Operations

Following is a list of conditions that are not normally found in the day-to-day operation of filtration systems; however, these conditions could occur at almost any time. Recommendations are added to aid you in adjusting to the situation.

1. High solids in the applied water due to bulking sludge, rising sludge, or solids washout in the secondary clarifier.
    a. Run *JAR TESTS*[10] and adjust chemical dosage as needed.
    b. Place more filters in service to prevent breakthrough.
    c. Prepare to backwash more frequently.
2. Low suspended solids in applied water; however, solids pass through filter.
    a. Run jar tests and adjust chemical dosage as needed. Test a combination of chemicals and polyelectrolytes.
    b. Place more filters in service to reduce velocity through the media.
    c. Backwash filter and pre-coat clean filter with *FILTER AID*.[11]
3. Loss of filter aid chemical feed.
    a. Place more filters in service to reduce velocity through media.
    b. Backwash more frequently.
    c. Pre-coat clean filters by hand feeding chemicals into them when first placed into service.
4. High wet weather peak flows.
    a. Place more filters in service.
    b. Run jar tests and adjust chemical dosage as needed.
    c. Prepare for peak daily flows by backwashing early.
5. Low applied water flows.
    a. Reduce number of filters in service. Run one-half of a filter at a time.
    b. Prepare to take one filter out of service and backwash when flow or head loss increases, thereby preventing breakthrough.
6. High color loading.
    a. Run jar tests and adjust chemical dosage as needed.
    b. Add chlorine to applied water.
    c. Usually color cannot be removed with filtration; consequently the problem must be corrected at the source.
7. High temperature.
    a. Run jar tests and adjust chemical dosage as needed.
    b. Prepare for *AIR BINDING*[12] of filters because water will release gases more readily at higher temperatures.
    c. Place more filters in service to reduce head loss through the media.
    d. Increase backwash water flow rates to obtain the same bed expansion as used when backwashing with colder water.
8. Low water temperature.
    a. Run jar tests and adjust chemical dosage as needed.
    b. Prepare for air binding of filters as cold water will carry more gases to the filters. Backwash more frequently if air binding occurs.
    c. Place more filters in service to reduce head loss through filter media.
    d. Reduce backwash water flow rates to obtain the same bed expansion as used when backwashing with warmer water.
9. Air binding.
    a. Backwash at a lower head loss.
    b. Place more filters on line to reduce head loss through media.
    c. Take filter out of service and allow air to escape to the atmosphere. This will reduce head loss; however, if placed back into service without backwashing, solids will likely be drawn through the media and into the effluent. These solids may or may not cause a problem.
10. Negative pressure in filter.
    a. Reduce flow through the filter by adding additional units.
    b. Backwash at a lower head loss.
    c. Skim surface of media (about one-half inch or 1.3 cm) to remove fines.
    d. Prevent filter from running at a low filtration rate. This builds a mat on the media surface and then sharply increases the head loss if a higher rate of water flows through the filter.
    e. A negative pressure within the filter will cause a false reading from the differential pressure sensor.

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[10] *Jar Tests. A laboratory procedure that simulates coagulation/flocculation with differing chemical doses. The purpose of the procedure is to* ESTIMATE *the minimum coagulant dose required to achieve certain water quality goals. Samples of water to be treated are placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of the solids is observed. The lowest dose of chemicals that provides satisfactory settling is the dose used to treat the water.*

[11] *Filter Aid. A chemical (usually a polymer) added to water to help remove fine colloidal suspended solids.*

[12] *Air Binding. The clogging of a filter, pipe or pump due to the presence of air released from water.*

11. High BOD and COD.
    a. Handle same as high suspended solids.
    b. Chlorinate applied water.
12. High coliform group bacteria levels.
    a. Chlorinate applied water to increase contact time.
    b. Place additional units in service to increase contact time.
    c. Run jar tests and adjust chemical dosage as needed to reduce suspended solids.
13. Chlorine in applied water.
    a. Discontinue adding polyelectrolytes as chlorine will interfere with them.
    b. Run jar tests and adjust chemical dosage as needed.
14. pH change in applied water.
    a. Run jar tests and adjust chemical dosage as needed.
    b. Change type of filter aid if necessary.
15. High grease and oil in applied water.
    a. If in solution, they will pass through media.
    b. If not in solution, they will be trapped in the bed, thus requiring extra hosedown during each backwash.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3N List at least five of the various types of abnormal operating conditions that could occur while operating a filtration system.

4.3O How would you adjust to a situation in which you were treating a high solids content in the water applied to a filter?

4.353 Operational Strategy

The development of an operational strategy for the filtration of wastewater will aid in dealing with situations such as sudden changes in applied water, in training new operators or in planning for the future. Following are points to consider when developing or reviewing your plans.

1. Maintain the filtering rates within the design limits. Add units or remove them from service as needed. Very low filtering rates will produce matting on the surface. This matting will cause breakthroughs if the flows are increased sharply. Excessively high rates will pull the solids through the filter and into the effluent.
2. Each backwash must be a complete cleaning of the media or solids will build up and form mudballs, or cause the media to crack.
3. To remove mudballs, first backwash thoroughly. Then super chlorinate manually and draw the chlorinated water into the filter media. Allow this chlorinated water to stand for 24 or 48 hours to soak the mudballs and finally backwash thoroughly again.
4. Run jar tests to maintain optimum chemical dosages. As the applied water quality changes (solids, alkalinity, temperature), the filter aid requirements will change. The operator must be aware of the changes and the effectiveness of the chemicals applied.
5. With complete backwashing, a high quality effluent can be maintained without filtering to waste before placing the filter back into service.
6. If the effluent turbidity reaches 3 to 4 *TURBIDITY UNITS,*[13] a change should be made to correct the problem. Either adjust chemical dosage, adjust flow rate or backwash the filter.
7. Filter walls that are constructed with a smooth surface (sacked) or painted with a good sealant are easy to keep clean. A rough surface provides an excellent area for algae and slimes to grow.
8. Controls and instrumentation must be protected from the elements. Cabinets that are opened to adjust instruments must be out of the rain, dust and extreme heat.
9. Air used to operate instruments or transmit signals must be *CLEANED AND DRIED* to prevent damaging the equipment.
10. Every three or four months, measure and record the freeboard to the filter media surface (Figure 4.23). A small amount of media loss is normal, but an excessive amount (2 to 3 inches or 5 to 7 centimeters) indicates operational problems.
11. After the filters have been in service for some time, obtain a profile of the media to determine if it is being displaced. A plug sample will show if the media are being regraded after each backwash.
12. When landscaping around uncovered filters, keep trees and shrubs that will drop leaves into the bed away from the filter because leaves are very difficult to backwash out of the media.
13. Never throw trash such as cigarette butts into the filter media. Trash may not backwash out and instead may work its way deep into the media.
14. Occasionally chlorinate ahead of the filters to control algae and slime growths on the walls and within the media. There will be a short period of discolored effluent after the initial application, but the water will turn clear in a short while.
15. Calculate the unit cost to treat wastewater. Apply this cost to the volume of water used per backwash. Inform all operators of this because it may easily cost in excess of $100 per filter wash.
16. Always fill an empty filter bed through the backwash system to prevent disturbing the media surface. If an empty filter is filled through the influent valve, water will flow into the washwater troughs, over the top edges and onto the top of the media. The force of this falling water will disturb the media.
17. Allow dry filter media to soak several hours before backwashing. Dry media will tend to float out with the backwash water.

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[13] *Turbidity units. Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

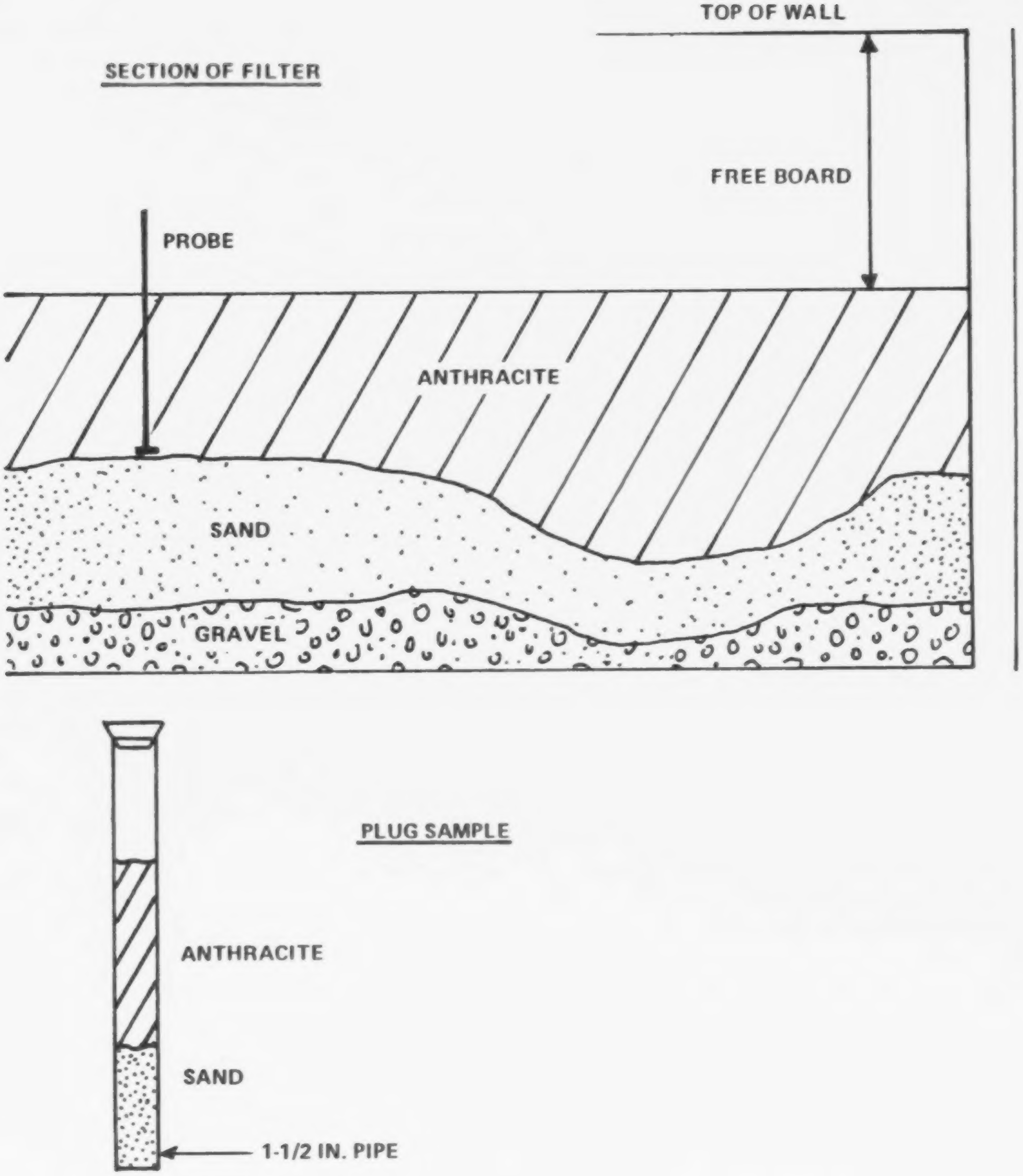

TOP OF WALL
SECTION OF FILTER
FREE BOARD
PROBE
ANTHRACITE
SAND
GRAVEL
PLUG SAMPLE
ANTHRACITE
SAND
1-1/2 IN. PIPE

Fig. 4.23 Section of filter and plug sample

18. Maintain a log (Figure 4.24) of the filtering operation which includes the following:
    a. Time filter was placed into service and total hours run between washings,
    b. Volume of water processed between washings,
    c. Applied water rate at start and end of filter run,
    d. Head loss at start and end of filter run,
    e. Applied suspended solids and BOD,
    f. Effluent suspended solids and BOD,
    g. Percent removal of suspended solids and BOD,
    h. Chemicals added as filter aids, mg/*L*,
    i. Chlorine added to applied water, mg/*L*,
    j. Remarks of special observations and maintenance,
    k. Backwash water flow rates and duration,
    l. Surface wash flow rate and duration, and
    m. Influent and effluent turbidity.

4.354 Shutdown of a Gravity Filter

If the filter is to be out of service more than a week, it should be dewatered and air dried. This will help control slime and algae growth on the walls, troughs and within the media. Dried algae can be hosed from the walls prior to backwashing and returning to service.

To remove a filter from service, switch controls to the manual mode of operation and then:

1. Close the influent valve,
2. Filter all the water possible through the rate-control valve, and
3. Open the drain valve.

Hose down and backwash the filter before returning it to service.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3P How would you determine if media are being lost from a filter?

4.3Q Why should trees and shrubs be kept away from uncovered filters?

4.36 Troubleshooting

PROBLEM: HIGH TURBIDITY AND SUSPENDED SOLIDS IN THE EFFLUENT.

1. Check for excessive head loss. Breakthrough will occur at a high head loss.
2. Look for fluctuating flows. Widely varying flows will cause breakthrough.
3. Determine filter aid dosages.
4. Examine backwash cycle for complete wash.
5. Inspect for damaged bed due to backwashing.

PROBLEM: RAPID BUILDUP OF HEAD LOSS.

1. Check applied water suspended solids.
2. Check filter aid dosage.
3. Determine applied water flow rate.
4. Check backwash cycle for complete wash.
5. Inspect head loss differential pressure sensor for air in one side. This will give a false reading.

PROBLEM: INSIGNIFICANT BUILDUP OF HEAD LOSS.

1. Check applied water suspended solids.
2. Check applied water flow rate.
3. Determine filter aid dosages.
4. Check head loss differential pressure sensor for air in one side. This will give a false reading.
5. Examine filter effluent for suspended solids going out (filter breakthrough).
6. Inspect for damaged bed due to backwashing.
7. Backwash and check for complete cycle.

PROBLEM: RAPID LOSS OF FILTER MEDIA.

1. Look for washout during backwash cycle.
2. Examine for media in effluent indicating a damaged filter underdrain.
3. Check for excessive scouring during backwash cycle time. Excessive scouring will grind the media into fines.

PROBLEM: HIGH HEAD LOSS THROUGH CLEANED FILTER.

1. Inspect differential pressure sensor for air in one side.
2. Check for incomplete backwash cycle.
3. Look for mudballs in filter media. Take a plug sample. (Fig. 4.23, page 314.)

PROBLEM: FLOW INDICATED WHEN EFFLUENT VALVE IS CLOSED.

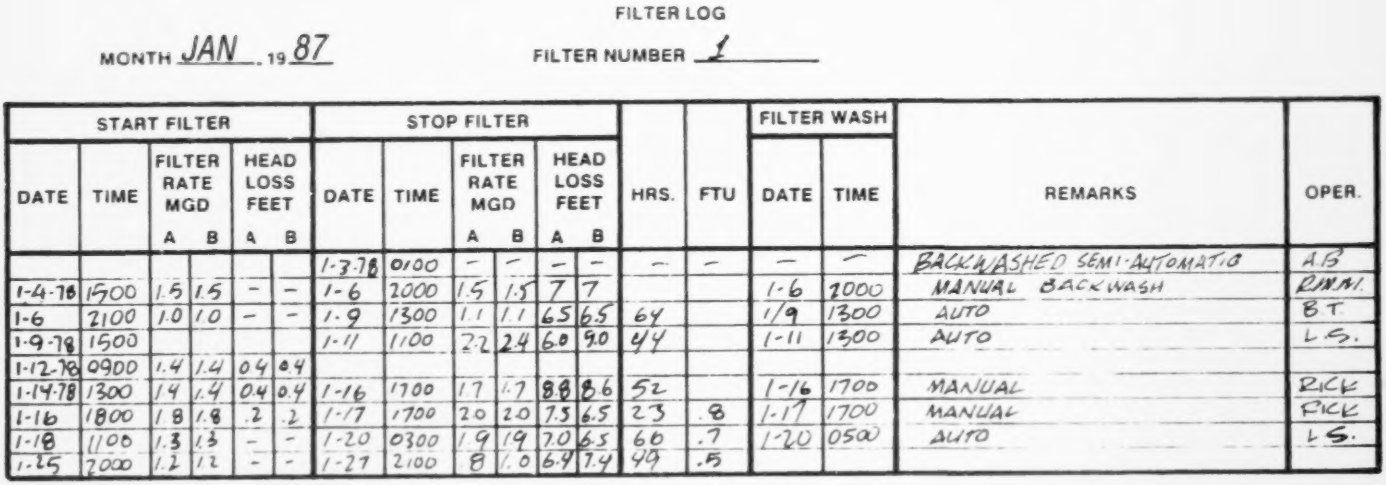
1. Inspect differential pressure sensor for air in one side.
2. Check instrumentation loop for calibration.
3. Examine valve for proper position.

PROBLEM: BACKWASH STOPS BEFORE COMPLETING CYCLE.

1. Look for sticking valve.
2. Inspect for electrical relay hang-up.
3. Check for timer out of sequence.
4. Examine backwash water supply.
5. Inspect electrical control (pump lock-out).

4.37 Safety

Always think safety when working around moving equipment and motors with automatic controls. Filtration systems have electrical, chemical and mechanical safety hazards. Operators are usually well protected from electrical hazards; however, there are times when opening a panel to look for trouble or to adjust a timer may expose you to electrical hazards. Always



FILTER LOG

MONTH JAN 19 87

FILTER NUMBER 1

START FILTER						STOP FILTER						HRS.	FTU	FILTER WASH		REMARKS	OPER.
DATE	TIME	FILTER RATE MGD		HEAD LOSS FEET		DATE	TIME	FILTER RATE MGD		HEAD LOSS FEET				DATE	TIME		
		A	B	A	B			A	B	A	B						
						1-3-78	0100	–	–	–	–	–	–	–	–	BACKWASHED SEMI-AUTOMATIC	A.B.
1-4-78	1500	1.5	1.5	–	–	1-6	2000	1.5	1.5	7	7			1-6	2000	MANUAL BACKWASH	R.W.M.
1-6	2100	1.0	1.0	–	–	1-9	1300	1.1	1.1	6.5	6.5	64		1/9	1300	AUTO	B.T.
1-9-78	1500					1-11	1100	2.2	2.4	6.0	9.0	44		1-11	1300	AUTO	L.S.
1-12-78	0900	1.4	1.4	0.4	0.4												
1-14-78	1300	1.4	1.4	0.4	0.4	1-16	1700	1.7	1.7	8.8	8.6	52		1-16	1700	MANUAL	RICK
1-16	1800	1.8	1.8	.2	.2	1-17	1700	2.0	2.0	7.5	6.5	23	.8	1-17	1700	MANUAL	RICK
1-18	1100	1.3	1.3	–	–	1-20	0300	1.9	1.9	7.0	6.5	60	.7	1-20	0500	AUTO	L.S.
1-25	2000	1.2	1.2	–	–	1-27	2100	.8	1.0	6.4	7.4	49	.5				

Fig. 4.24 Log of filter operation

use safety equipment (rubber electrical gloves, voltage test meters, fuse pullers, and lock-out switches) and approved safety procedures when working with electricity.

Chemical hazards include chemical burns and skin irritation from direct contact with chemicals. Also, there is the hazard of slipping and falling caused by chemical spills. Good housekeeping will reduce the safety hazards caused by chemicals.

Mechanical hazards associated with filters are similar to those found throughout the treatment plant. Safety guards must be in place, equipment operated automatically must be identified by warning signs, and work areas should be well lighted.

4.38 Review of Plans and Specifications

While reviewing the plans and specifications of a gravity filtration system, you should consider the items listed in this section.

1. Filters require regular servicing; therefore, provisions must be made to handle the normal flows during periods of servicing. Regular maintenance includes servicing of valves, instruments and filter media.
2. The quality of the water applied to the filters must be considered when a filtering media is specified. A high suspended solids content in the applied water will quickly plug a fine-media filter, thereby requiring frequent backwashing.
3. Install sufficient instrumentation to adequately monitor the process and to determine operating efficiencies. Include instrumentation to measure and record applied flows, backwash flows, head loss, and water quality before and after filtration.
4. Be sure that each step in the automatic system is complete before the following or next step can begin.
5. Provide a means to reset the automatic system if the backwash cycle is interrupted.
6. Keep the automatic backwashing system uncomplicated, especially in small plants. The operator should be on hand at the start of a filter backwash cycle. Housekeeping chores can be performed while keeping an eye on the filter washing process.
7. Install instruments out of the weather and well protected from the weather. Even weather-proof cabinets must be opened during the maintenance and servicing of instruments and equipment.
8. Install the instruments' read-out meters, charts and gages in a convenient and centralized location.
9. Separate and shield instrumentation signals from all high voltage (110 volts and higher) and from other equipment noise that may be picked up by the instruments as a false signal.
10. Provide adequate storage for chemicals. A minimum supply of chemicals must be on hand even while waiting for a full shipment.
11. Provide adequate storage for both the backwash water supply and the used backwash water.
12. When reviewing designs for the future, keep today's flows in mind. Equipment operating below 10 percent capacity may be useless for years.
13. Visit similarly designed plants that are currently in operation and talk to the operators regarding possible design improvements.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 333.

4.3R What are the three main types of safety hazards around filtration systems?

4.3S When reviewing plans and specifications for a filtration system, instrumentation should be available to measure and record what items?

4.3T Where should the instruments' read-out meters, charts and gages be installed?

END OF LESSON 3 OF 4 LESSONS
ON
SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

DISCUSSION AND REVIEW QUESTIONS

(Lesson 3 of 4 Lessons)

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 2.

13. Why are multi-media filters used?
14. How can a filter bottom be damaged?
15. What is the purpose of instrumentation used with a filter system?
16. How does a rapid-sand filter work?
17. Why should you attempt to maintain filtering rates within the design limits?
18. How would you remove a gravity filter from service?

CHAPTER 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

By Ross Gudgel

(Lesson 4 of 4 Lessons)

4.4 SOLIDS REMOVAL FROM SECONDARY EFFLUENTS USING INERT-MEDIA PRESSURE FILTERS

4.40 Use of Inert-Media Pressure Filters

Inert-media pressure filters remove suspended solids and turbidity from the secondary effluent after the addition of chemical coagulants such as a polymer and/or alum. The filtration process is used to meet waste discharge requirements for final effluent suspended solids and turbidity limits established by an NPDES permit when these limits cannot be met by secondary treatment processes. Filtration also will have a direct bearing on the disinfection of the final effluent by the removal of more solids from the water to be disinfected. Fewer solids will reduce the amount of chlorine necessary to meet the NPDES permit coliform requirements.

The filter system usually consists of:

1. A holding tank or wet well for secondary effluent storage,
2. Filter feed pumps which pump the secondary effluent from the holding tank to the filters,
3. A chemical coagulant feed pump system which injects the necessary coagulants into the influent line to the filters,
4. Single, dual, or multi-media filters that trap the suspended solids and remove the turbidity,
5. A filter backwash wet well for clean backwash water storage,
6. Filter backwash pumps which pump clean water back through the filter to remove the trapped suspended solids, and
7. A decant tank that provides for holding the spent backwash water to allow the suspended solids to settle while the clarified water is either directly recycled to the filtlers or is returned to the headworks.

Figure 4.25 shows a schematic view of the items outlined above and further discussed in the following sections.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 334.

4.4A What is the purpose of the inert-media pressure filter?

4.4B What chemicals are commonly used with the filtration process and why?

4.4C List the major components of a pressure filter system.

4.41 Pressure Filter Facilities

The following sections describe facilities which are typical for a filter plant with a capacity of 5 MGD. Facilities at larger or smaller plants would be quite similar but might differ significantly in the numbers and sizes of the various components.

4.410 Holding Tank (Wet Well)

Secondary effluent from the treatment plant's secondary sedimentation tanks is conducted through a channel or pipe to a holding tank. The purpose of this tank is to store water and to allow additional settling to the suspended solids before the water is applied to the filters. Most tanks of this type are very similar to secondary clarifiers. They have flights or scrapers to move the settled solids towards a sludge hopper for return to the solids handling facility.

A bypass structure should be provided to permit secondary effluent to bypass the pressure filters during emergency conditions, such as equipment failures or clogged filters. Bypassed flows should go into emergency holding basins or into the chlorine contact tank for final treatment before discharge. An alternate emergency storage procedure would be to divert secondary effluent into the decant tank.

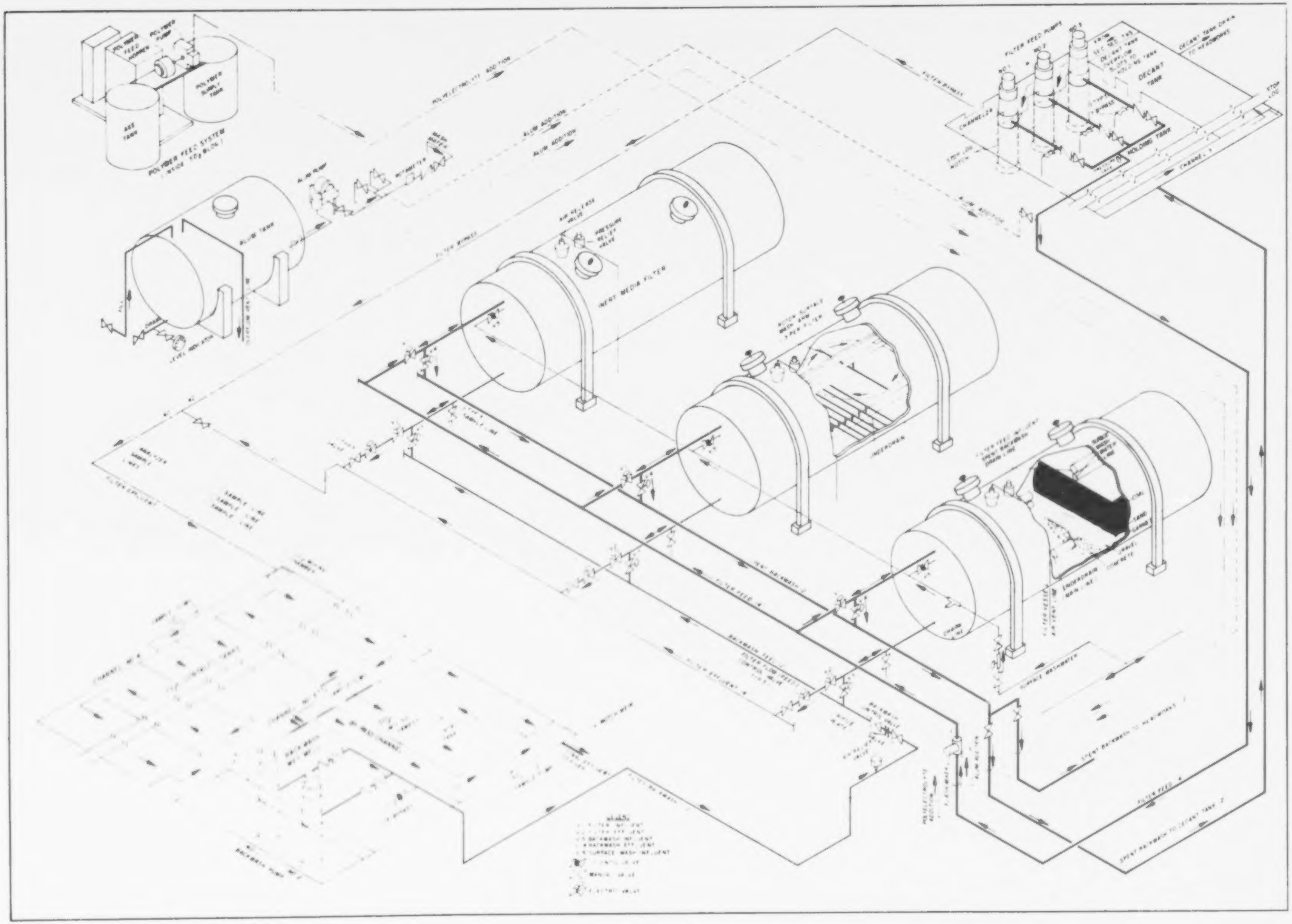

POLYMER FEED HOPPER
POLYMER PUMP
POLYMER SUPPLY TANK
AGE TANK
POLYMER FEED SYSTEM
POLYELECTROLYTE ADDITION
ALUM PUMP
ROTAMETER
ALUM TANK
ALUM ADDITION
FILTER BYPASS
AIR RELEASE VALVE
PRESSURE RELIEF VALVE
INERT MEDIA FILTER
UNDERDRAIN
FILTER FEED PUMPS
NO. 1
NO. 2
NO. 3
DECANT TANK
HOLDING TANK
CHANNEL 1
FILTER EFFLUENT
SAMPLE LINE
FILTER FEED
BACKWASH FEED
SURFACE WASHWATER
SPENT BACKWASH TO HEADWORKS
SPENT BACKWASH TO DECANT TANK
COAL
SAND
GRAVEL
CONCRETE
UNDERDRAIN MANIFOLD
DRAIN LINE
BACKWASH PUMP
FILTER INFLUENT
FILTER EFFLUENT
BACKWASH INFLUENT
BACKWASH EFFLUENT
SURFACE WASH INFLUENT
CONTROL VALVE
MANUAL VALVE
ELECTRIC VALVE

Fig. 4.25 Schematic view of pressure filter system

Spent backwash water may also be returned to the decant tank. Both flows receive some settling and the clarified effluent then overflows into the holding tank through weir slots between the two tanks for recycle to the filters. In either method of operation, the floatable materials in the holding tank are collected and discharged to the solids handling section of the plant for disposal. For additional information on clarifier operation and maintenance, see Chapter 5, "Sedimentation and Flotation," Volume I, *OPERATION OF WASTEWATER TREATMENT PLANTS.*

4.411 Filter Feed Pumps (Figure 4.26)

Filter feed pumps lift the secondary effluent from the holding tank and pump it through the filters. Generally they are of the vertical-turbine wet-pit type pump with either a closed or semi-open impeller. The pumps are driven by either fixed-speed, multi-speed (two speed), or variable-speed motors or a combination of these. Each pump should be equipped with a manually adjusted bypass valve to avoid the possibility of the system operating at the shutoff pressure of the pumps. If this happens, the pumps could be damaged because no water would flow through the pumps. Each valve should be adjusted to allow a given bypass flow as recommended by the manufacturer.

The water level in the holding tank may be sensed by a level transmitter. The transmitter provides a signal used for starting and stopping of the pumps and for a set point signal for the controller which controls filter flow.

Starting and stopping of the pumps is controlled by a HAND-OFF-AUTO (HOA) switch for each pump. Another switch is used to select the sequence of automatic starting (lead or lag). Normal automatic start-stop control of the pumps may be by means of current trips using the signal representing the water level in the holding tank. A low-water probe in the holding tank will stop all pumps if the water level drops below a pre-set elevation. For additional information on the operation and maintenance of pumps, see Chapter 15, "Maintenance," Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS.*

4.412 Chemical Feed Systems

Various types of chemicals may be added to the filter influent flow to insure coagulation and flocculation of the suspended material. This coagulation and flocculation aids the filtering process by joining many of the finely divided and colloidal suspended solids into a floc mass which is easily trapped on or in the filter media, thus allowing clear water to pass through the filter. Alum and polymers are the most common chemicals used.

A discussion of the reasons for using chemicals and the method of feed is contained in this section.

ALUM (ALUMINUM SULFATE) (Figure 4.27)

Alum is a coagulant which produces a hydrous oxide floc. This floc causes suspended material to stick together by electrostatic or interionic force when contact of the chemical and a solid particle is made in the filter influent flow.

The alum may be pumped by a mechanical diaphragm, positive displacement pump. The dosage is manually adjusted by adjustment of the pump stroke length. Motor speed may be controlled by a silicon controlled rectifier (SCR) drive unit that uses a filter-flow signal to pace the pump in the automatic mode. The SCR drive is also equipped with a manual potentiometer for manual speed control and a meter indicating percentage of total or full motor speed.

The pump discharge check valve has a built-in back pressure device to prevent nonlinear delivery due to low discharge pressure and to prevent siphoning. All wetted parts of the pump are selected for their chemical resistance.

POLYMERS (POLYELECTROLYTES)

Polymers are flocculation aids which are classified on the basis of the type of electrical charge on the polymer chain. Polymers possessing negative charges are called "anionic," positive charged polymers are called "cationic," and polymers that carry no electrical charge are called "nonionic." Polymers cause the suspended material to stick together by chemical bridging or chemical enmeshment when contact is made in the filter influent flow.

Generally only the "anionic" polymers are used in conjunction with alum.

Polymer usually is injected into the influent line of the filters downstream from the point of alum injection.

The polymer may be prepared for use (dilution and aging) by a polyelectrolyte mixer unit. This unit consists of a dry polymer feeder with storage hopper, a solution-water flow meter with regulating valve, pressure regulating valve, pressure gage, solenoid valves, dilution water flow meter with regulating valve, polymer wetting cones, a mixing/aging tank, slow-speed mixer, transfer pump, metering/storage tank, and a metering pump with SCR drive.

The dry feeder is a screw-type feeder capable of metering dry polymer of densities ranging from 14 to 42 lbs/cu ft (225 to 675 kg/cu m) at an adjustable rate to the wetting cones in order to prepare various solution concentrations.

The mixing/aging tank and the metering/storage tank are sized based on the projected use of polymer. The tanks usually are made of steel and are provided with a fiberglass liner. The mixer, a low-shear type (to avoid breaking up floc), is fitted with a stainless steel shaft and impellers.

The slow speed, positive displacement, "progressing cavity" type transfer pump conveys the mixed polymer solution from the mixing/aging tank to the metering/storage tank with minimal polymer shear. The metering pump is capable of delivering various amounts of polymers at various percent solutions. Flow pacing, adjustment of the dosage rate, and operation of the polymer metering pump are the same as for the alum feed pump.

EXAMPLE 1

Known		Unknown
Polymer Delivered, lbs/day	= 72 lbs polymer/day	Polymer Dose, mg/*L*
Flow Through Filter, gpm	= 6000 gpm	

Determine pounds of polymer per million pounds of water which is the same as mg per million mg or mg/*L*.

$$\begin{aligned}\text{Polymer Dose, mg}/L &= \frac{\text{Polymer delivered, lbs polymer/day}}{\text{Flow through filter, M lbs water/day}}\\ &= \frac{72 \text{ lbs polymer/day}}{6000 \text{ gal/min} \times 8.34 \text{ lbs/gal} \times 60 \text{ min/hr} \times 24 \text{ hr/day}}\\ &= \frac{72 \text{ lbs polymer/day}}{72{,}057{,}600 \text{ lbs water/day}}\\ &= \frac{72 \text{ lbs polymer/day}}{72 \text{ M lbs water/day}}\\ &= 1 \text{ mg polymer/liter water}\\ &= 1 \text{ mg}/L\end{aligned}$$

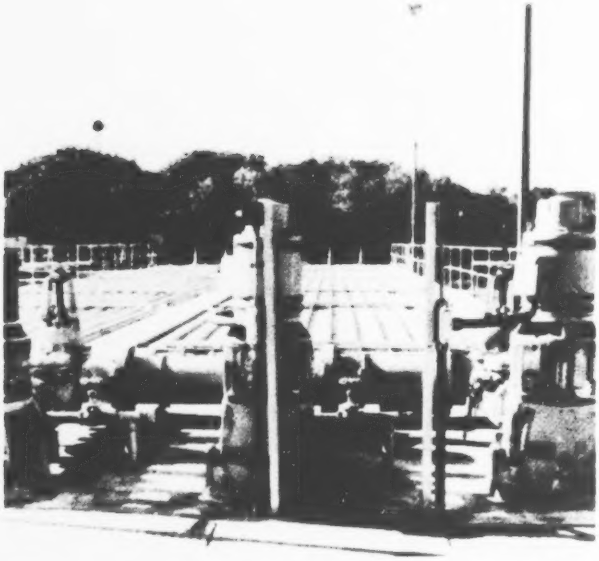


Fig. 4.26 Filter feed pumps

Fig. 4.27 Alum storage tank and feed pump

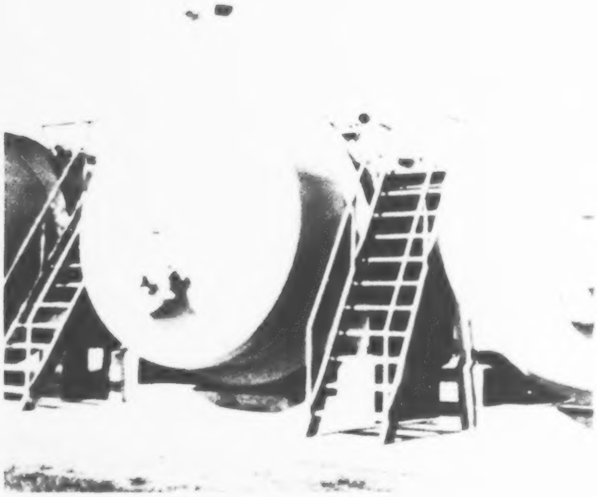


Fig. 4.28 Filter vessels

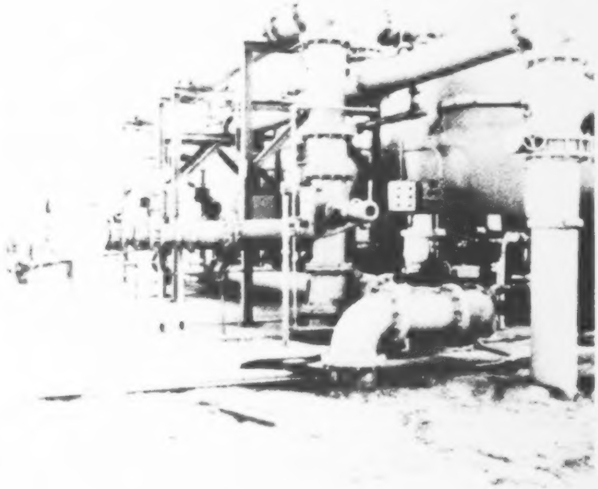


Fig. 4.29 Filter vessels

A variable-area flow meter (rotameter) is provided to indicate flow of dilution water to the metered polymer (Figure 4.30). The polymer is mixed automatically by the polyelectrolyte mixer. The dry feeder is calibrated to dispense a metered quantity of dry polymer to obtain a desired solution concentration. The dry polymer drops to the wetting cones from the feeder hopper, where it is spread on a high velocity water surface and the individual grains of polymer are wetted to form a polymer solution. This solution then flows to the aging tank where it is mixed and aged. On completion of the aging cycle, the polymer solution is pumped to the metering/storage tank by the transfer pump. When the aging tank empties, the polymer preparation and mixing cycle begins again. The metering pump, calibrated to deliver a desired dosage, draws the polymer solution from the metering/storage tank and delivers it to the influent line of the filters.

Steps to calculate polymer and alum dosage are outlined in the following examples. Information concerning the concentration of chemical (lbs/gal) delivered to your plant may be obtained from the chemical manufacturer or supplier.

EXAMPLE 2.

Determine polymer dosage, mg/*L*. Polymer is supplied to your plant at a concentration of 0.5 pounds polymer per gallon (60 gm/*L* or 60 kg/cu m). The polymer feed pump delivers a flow of 0.10 gpm (0.0063 *L*/sec) and the flow to the filter is 3,000 gpm (190 *L*/sec). Calculate the concentration or dose of polymer in the water applied to the filter.

Known		Unknown
Polymer Conc., lb/gal	= 0.5 lbs/gal	Polymer Dose, mg/*L*
Polymer Pump, gpm	= 0.1 gpm	
Flow to Filter, gpm	= 3000 gpm	

ENGLISH

Calculate polymer dose, mg/*L*

$$\begin{aligned}\text{Dose, mg}/L &= \frac{\text{Flow, gal/min} \times \text{Conc., lbs polymer/gal}}{\text{Flow, gal/min} \times 8.34\text{ lbs water/gal}}\\ &= \frac{0.1\text{ gal/min} \times 0.5\text{ lbs polymer/gal}}{3000\text{ gal/min} \times 8.34\text{ lbs water/gal}}\\ &= \frac{0.05\text{ lbs polymer}}{25{,}020\text{ lbs water}} \times \frac{1{,}000{,}000^{*}}{1\text{ M}}\\ &= \frac{2.0\text{ lbs polymer}}{1\text{ M lbs water}}\\ &= \frac{2.0\text{ mg polymer}}{1\text{ M mg water}^{**}}\\ &= 2.0\text{ mg}/L\end{aligned}$$

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* We multiplied the top and the bottom by the same number, 1,000,000 or 1 M. This is similar to multiplying the top and bottom by 1, you do not change the equation.

** 1 M mg water = 1 liter.

METRIC

$$\begin{aligned}\text{Dose, mg}/L &= \frac{\text{Flow, }L\text{/sec} \times \text{Conc., gm polymer}/L \times 1000\text{ mg/gm}}{\text{Flow, }L\text{/sec}}\\ &= \frac{0.0063\ L\text{/sec} \times 60\text{ gm polymer}/L \times 1000\text{ mg/gm}}{190\ L\text{/sec}}\\ &= \frac{380\text{ mg polymer/sec}}{190\ L\text{ water/sec}}\\ &= 2\text{ mg}/L\end{aligned}$$

EXAMPLE 3. Determine alum dosage, mg/*L*

Liquid alum usually is supplied at a concentration of 5.4 pounds alum per gallon (650 gm/*L* or 650 kg/cu m). In this example, the alum feed pump delivers 88 ml per minute and the flow to the filter is 3,000 gpm (190 *L*/sec). Calculate the concentration or dose of alum in the water applied to the filter.

Known		Unknown
Alum Conc., lb/gal	= 5.4 lbs/gal	Alum dose, mg/*L*
Alum Pump, ml/min	= 88 ml/min	
Flow to Filter, gpm	= 3000 gpm	

ENGLISH

Calculate alum dose, mg/*L*

$$\begin{aligned}\text{Dose, mg}/L &= \frac{\text{Flow, ml/min} \times \text{Conc., lbs alum/gal} \times 0.00026\text{ gal/ml}^{*}}{\text{Flow, gal/min} \times 8.34\text{ lbs water/gal}}\\ &= \frac{88\text{ ml/min} \times 5.4\text{ lbs alum/gal} \times 0.00026\text{ gal/ml}}{3{,}000\text{ gal/min} \times 8.34\text{ lbs water/gal}}\\ &= \frac{0.125\text{ lbs alum}}{25{,}020\text{ lbs water}} \times \frac{1{,}000{,}000}{1\text{ M}}\\ &= \frac{5\text{ lbs alum}}{1\text{ M lbs water}}\\ &= 5\text{ mg}/L\end{aligned}$$

---

* Conversion factor. 1 ml = 0.00026 gallons

METRIC

$$\begin{aligned}\text{Dose, mg}/L &= \frac{\text{Flow, ml/min} \times \text{Conc., gm polymer}/L \times 1000\text{ mg/gm}}{\text{Flow, }L\text{/sec} \times 60\text{ sec/min} \times 1000\text{ ml}/L}\\ &= \frac{88\text{ ml/min} \times 650\text{ gm polymer}/L \times 1000\text{ mg/gm}}{180\ L\text{/sec} \times 60\text{ sec/min} \times 1000\text{ ml}/L}\\ &= \frac{950\text{ mg/sec}}{190\ L\text{/sec}}\\ &= 5\text{ mg}/L\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 334.

4.4D What is the purpose of the holding tank?

4.4E Cross out the incorrect words within the following parentheses in order to make the statement correct.

Alum is used for *(COAGULATION OR FLOCCULATION)* while polymers are used for *(COAGULATION OR FLOCCULATION)*.

4.4F Polymer is supplied at a concentration of 0.6 pounds polymer per gallon (72 gm/*L* or 72 kg/cu m). The polymer feed pump delivers a flow of 0.15 gpm (0.0095 *L*/sec) and the flow to the filters is 5,000 gpm (135 *L*/sec). Calculate the concentration or dose of polymer in the water applied to the filter.

4.413 ***Filters*** (See Figure 4.25, page 319)

This section discusses the purpose of the parts of the filters.

VESSELS (Figure 4.28 and 4.29, page 321)

In our example, each pressure vessel containing filter media consists of a cylindrical shell closed at both ends. Manways are provided to allow entry to the vessel for media installation and maintenance work. Pressure gages are attached to the manway covers to facilitate monitoring of the vessel pressure.

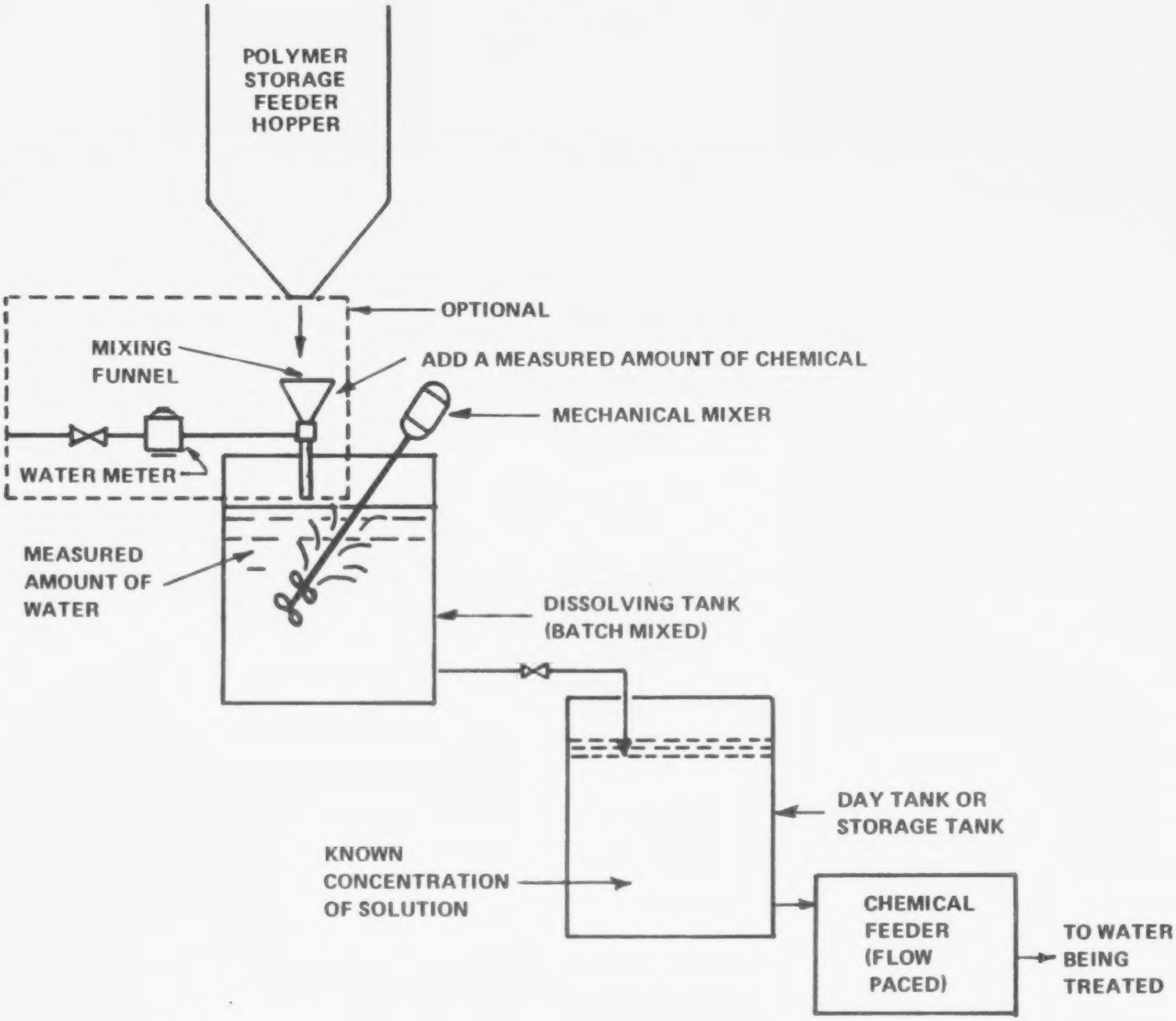

POLYMER
STORAGE
FEEDER
HOPPER
OPTIONAL
MIXING
FUNNEL
ADD A MEASURED AMOUNT OF CHEMICAL
MECHANICAL MIXER
WATER METER
MEASURED
AMOUNT OF
WATER
DISSOLVING TANK
(BATCH MIXED)
DAY TANK OR
STORAGE TANK
KNOWN
CONCENTRATION
OF SOLUTION
CHEMICAL
FEEDER
(FLOW
PACED)
TO WATER
BEING
TREATED

Fig. 4.30 Polymer dissolver, day tank and feeder

A direct spring-loaded pressure relief valve is installed on top of the filter and is set to release at a preset pressure. The relief valve is provided to prevent vessel rupture in case effluent flow is restricted or stopped while influent flow continues.

A combination-type air-release valve with a large orifice is also installed on top of the filter to permit air to exhaust when the filter vessel is charged with water and to allow air to reenter when the filter vessel is drained. A small orifice is also provided to exhaust small pockets of air which may collect during operation of the filter.

INTERIOR PIPING (Figure 4.25, page 319)

Interior vessel surfaces, influent and effluent headers, and supports are painted with a protective coating to inhibit corrosion. The influent header is suspended and supported from the upper side of the vessel by lugs. Each filter is equipped with rotary surface wash arms that are installed and supported just beneath the influent header. These are self-propelling, revolving "straight line" wash arms.

The surface wash piping consists of an influent water line, solenoid valve, a central bearing of all-bronze construction, a bronze tee having a nozzle affixed to emit a water stream directly below and from the center of the tee, and arms extending laterally from the tee. The lateral arms are fitted with numerous brass nozzles located at double-angle positions to most effectively cover the area of the filter bed to be cleaned. Each nozzle is fitted with a synthetic rubber cap slitted to act as a check valve to keep filter media away from the nozzle.

Water to the wash arms is supplied from an external source, usually from the treatment plant wash water system. Water from the surface wash arms quickly breaks up the mat of suspended material that has accumulated in and on the top layer of filter media. This occurs during the first portion of the backwash cycle.

The effluent header is encased in concrete fill in the lower section of the filter. PVC underdrain laterals are attached to the effluent header. Each lateral has numerous small diameter holes facing toward the bottom of the filter. The ends of the laterals are capped. The filtered water is collected by the underdrain laterals which passes the water to the effluent header for discharge from the filter.

UNDERDRAIN GRAVEL (Support Media)

The inert filtering media is supported by underdrain gravel consisting of specifically sized, hard, durable, rounded stones with an average specific gravity of not less than 2.5. The gravel is placed in the filter in many specific layers starting with the larger stones (2-inch or 5-cm diameter) on the bottom and progressing to the smallest stones (¼-inch or 0.7-cm diameter) on top. The depth of each layer, specific stone sizes, and overall gravel depth will depend on the application, type, and quantity of inert media that will be used in a filter.

INERT MEDIA

Granular filter media commonly used in wastewater filtration include anthracite coal, silica sand, and garnet sand. These filter media range in size from 0.20 mm to 1.20 mm and specific gravities range from 1.35 to 4.5. The largest size media, anthracite coal, has the lowest specific gravity. Conversely, the smallest media, garnet sand, has the highest specific gravity.

Inert-media filter configurations vary according to the specific characteristics of the water to be filtered. The common applications use either silica sand or garnet sand as a single-media; anthracite coal and silica sand or garnet sand as a dual-media; and anthracite coal, silica sand, and garnet sand as a multi-media or mixed media filter.

In most filter applications, any of the various media used are placed in the filter with 60 percent of the larger size, lower specific gravity media on top, 30 percent of the medium size and specific gravity in the middle, and 10 percent of the smaller size, higher specific gravity media on the bottom. Thus, the smaller size filter media is placed on the support media first, followed by the medium size filter media and then the larger size filter media. Total filter media depth varies with the application.

Due to the size and density ratio of the media and its placement in the filter, the larger size and lower specific gravity media stay at the top and the smaller size higher specific gravity media remain at the bottom. Most dual-media filters are designed to keep the media separated after backwashing.

FLOW CONTROL METHOD (Figure 4.31)

In filter operation, the rate of flow through a filter is expressed in gallons per minute per square foot:

$$\text{Rate of flow, gpm/sq ft} = \frac{\text{Driving force}}{\text{Filter resistance}} = \frac{\text{Total available head}}{\text{Total head loss}}$$

Therefore, as the total head loss increases, the ratio of flow decreases. The driving force refers to the pressure drop across the filter which is available to force the water through the filter. At the start of the filter run, the filter is clean and the driving force need only overcome the resistance of the clean filter media. As filtration continues, the suspended solids removed by the filter collect on the media surface or in the filter media, or both, and the driving force must overcome the combined resistance of the filter media and the solids removed by the filter.

The filter resistance (head loss) refers to the resistance of the filter media to the passage of water. The head loss increases during a filter run because of the accumulation of the solids removed by the filter. The head loss increases rapidly as the pressure drop across the suspended solids mat increases, because the suspended solids already removed compress and become more resistant to flow. As the head loss increases, the driving force across the filter must increase proportionally to maintain a constant rate of flow.

The constant-rate method of filtration is commonly used for pressure filters. In this method, a constant pressure is supplied to the filter and the filtration rate is then held constant by the action of a manually or automatically operated filter rate-of-flow controller. At the beginning of the filter run, the filter is clean and has little resistance. If the maximum available water pressure was applied to the filter, and the effluent flow was not restricted, the flow rate would be very high. To maintain a constant flow rate, some of the available pressure is dissipated by the rate of flow controller (RFC). At the start of the filter run, the RFC is nearly closed to provide the additional head loss needed to maintain the desired flow rate. As filtration continues, the filter gradually becomes clogged with suspended solids and the RFC opens proportionally. When the valve is fully opened, any further increase in the head loss will not be balanced by a corresponding decrease in the head loss of the RFC. Thus, the ratio of pressure to filter resistance will decrease, and the flow rate will decrease. This action is also known as filter differential pressure. When the flow rate decreases, filter differential pressure increases and this is an indication that the filter run must be terminated and a filter backwash should be initiated.

4.414 Backwash System

As the suspended material accumulates on the filter media surface, or in the filter media bed, or both, the differential pressure across the filter increases, flow through the filter decreases, and filter effluent quality deteriorates. The filter

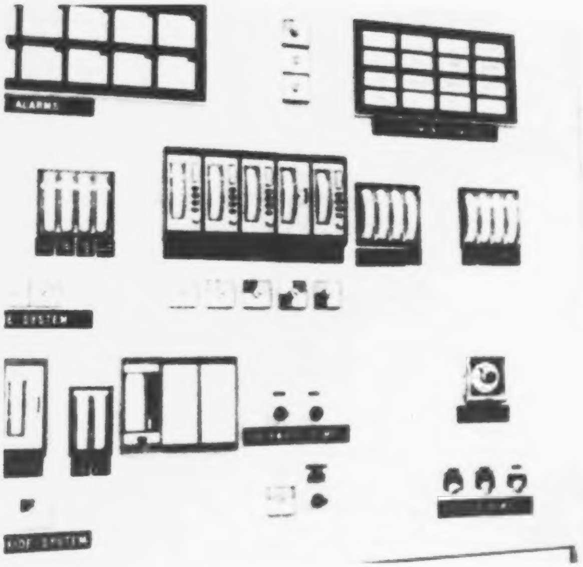


Fig. 4.31 Filter controls

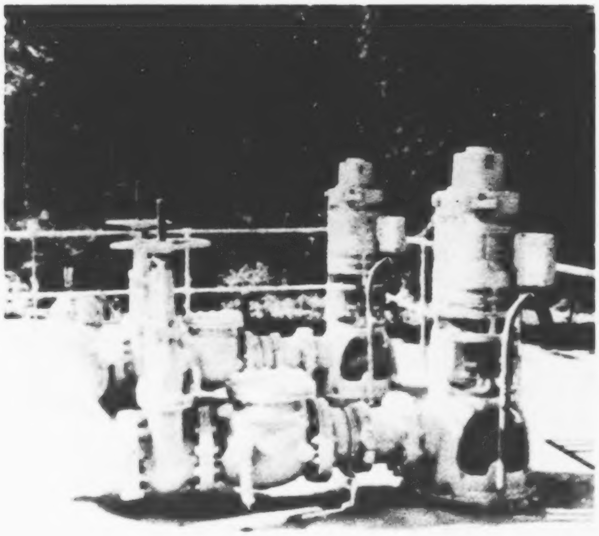


Fig. 4.32 Backwash pumps

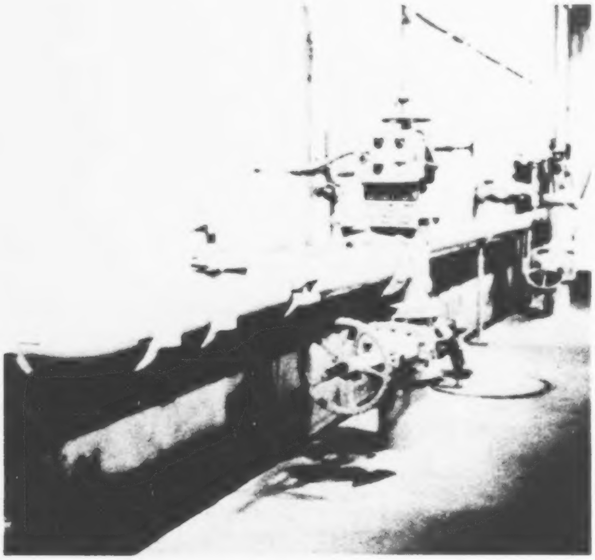


Fig. 4.33 Decant tank drain line automatic valves

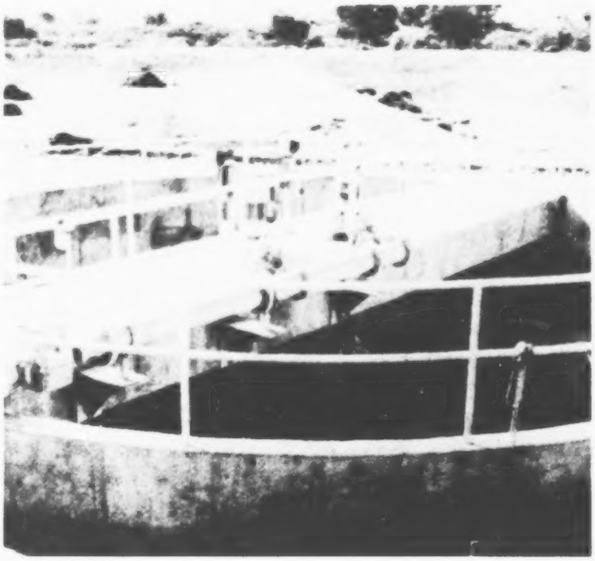


Fig. 4.34 Backwash recovery tank and feed pumps

backwash cycle removes the suspended solids accumulation from the filter, thus restoring the filter efficiency.

WET WELL

The backwash wet well is used to store a large volume of filtered and/or chlorinated wastewater to backwash the filters. The water, usually from the chlorine contact tank, flows to the wet well until it is filled up and then it flows to further final treatment processes. This flow method insures a continuous water supply to the wet well.

PUMPS (Figure 4.32, page 325)

The filter backwash pumps lift the filtered and/or chlorinated wastewater from the backwash wet well and pump it through the filters to remove the trapped suspended material. The pumps are generally of the vertical-turbine wet-pit type with either a closed or semi-open impeller. The pumps may be driven by fixed-speed motors.

The pump system is equipped with a solenoid-operated bypass valve installed on the common discharge line to prevent the possibility of the system operating at the shut-off pressure of the pumps. A pressure switch with an adjustable operating range (psi) will cause the valve to open upon rising pressure. The bypass flow is returned to the backwash wet well. The common discharge line is also equipped with an air relief valve that purges air from the system to prevent air slugs from disturbing the filter media bed.

Normal start-stop of the pumps may be controlled by means of current switches in the backwash program unit. Lead-lag position selector switches provide the means of selecting the sequence of starting for the pumps. A low water probe in the backwash wet well will stop the pumps in the event that the water level drops below a pre-set elevation.

The backwash pump common discharge line is provided with an orifice plate and flow-control valve. Flow control is accomplished by means of a cascade control system using a cam programmer to provide a setpoint signal. A cam is cut so as to gradually introduce the backwash flow to the filters, thereby avoiding sudden disturbance or uneven expansion of the filter media bed.

BACKWASH CYCLE

Whenever possible, the filters should be backwashed during the plant's low flow hours when the full capacity of the filters is not needed. The backwash cycle may be activated either manually, automatically by a pre-set filter differential-pressure level, or automatically by a program timer. In the manual mode, only a desired filter may be backwashed. In the automatic modes all filters in the system that are "ON LINE" may be washed when the differential pressure reaches the pre-set level. Upon completion of backwash of one filter, the next filter in an "ON LINE" status will begin to backwash.

The total backwash duration per filter usually is adjustable. The total backwash flow and duration should be adequate to fluidize and expand the media bed. The largest media size and the warmest expected water temperature will dictate the maximum filter backwash rates required.

When the backwash cycle is manually or automatically activated, the following sequence occurs:

1. Filter influent valve (V-1) and effluent valve (V-2) close to terminate filter feed flow. (See Figure 4.25, page 319, for locations of valves.)
2. Backwash influent valve (V-3) and effluent valve (V-4) open to allow backwash flow into and out of the filter.
3. The surface wash arms' influent water line solenoid valve (V-5) opens allowing the wash arms to function in initially breaking up the mat of suspended material that has accumulated on the top layer of filter media.
4. The backwash pumps start pumping against a closed backwash control valve. The backwash flow rate is brought up to full rate in one to two minutes as determined by the cam programmer transmitting a gradual "open" signal to the backwash flow-control valve operator.

   As the surface wash continues to operate, the backwash flow gradually enters the filter from the bottom. As the flow increases, the bed fluidizes and expands upward (about 20 percent of the total media depth) allowing a uniform rolling action of the filter media bed which results in cleaning of the media due to the hydrodynamic shear (water causes grains to clean each other) that occurs. The media bed expands upward and into the rotating surface wash arms. The arms now aid in breaking up the suspended material and mud balls that have accumulated in the top section of the media.
5. After two to five minutes of surface wash, the surface wash influent water line solenoid valve closes. Surface wash is discontinued two to ten minutes before the backwash ends so that the surface of the filter media will be smooth and level at the beginning of the cleaned filter run cycle.
6. After seven to twenty minutes of backwash, the backwash flow-control valve gradually begins to close. Shortly after the backwash flow-control valve is fully closed, the backwash pumps stop.
7. Backwash influent valve (V-3) and effluent valve (V-4) close.
8. Filter influent valve (V-1) and effluent valve (V-2) open.

NOTE: When the backwash cycle is activated, the filter flow-control valve fully closes. Upon completion of the cycle the valve opens slightly.

The valve sequence indicated in items 1, 2, 8 and 9 occurs simultaneously to insure that the filter does not become "air bound" (clogged by air released from water). Air binding will reduce or block filter influent flow and/or create media bed disturbance when filter backwash begins.

4.415 **Decant Tank** (Backwash Recovery) (Figures 4.33 and 4.34, page 325)

Most decant tanks are very similar to secondary clarifiers because they have flights or scrapers to collect settled material toward a sludge hopper.

Filter backwash effluent leaves the filter and may be discharged to the decant tank. The suspended material in the backwash water is allowed to settle and the clarifier effluent overflows to the holding tank through weir slots between the two tanks for recycle to the filters. The settled material is collected toward a hopper in the tank for periodic discharge to the solids handling facility.

If poor settling occurs in the decant tank, all spent backwash flow may be returned to the head end of the plant through the tank drain line. The drain line may be equipped with a propeller meter and a motor-operated butterfly valve. The common opening limit of the valve should be set to discharge tank flow at a rate which will not hydraulically overload the plant.

The tank may be equipped with high water level probes which will open the motor-operated valve fully to allow a predetermined volume of water to leave the tank rapidly. This may be necessary if the tank becomes surcharged (overloaded) due to frequent filter backwashes.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 334.

4.4G List the major components of pressure filters.

4.4H How is the mat of suspended material on the media surface initially broken up during a backwash?

4.4I What is the source of water used to backwash the filter?

4.4J What is the purpose of the decant tank?

4.42 Operation

4.420 Operational Strategy

This lesson has covered some of the basic concepts of inert-media pressure filters used to remove suspended solids and turbidity from secondary effluents before chlorination.

If the filters become overloaded due to high suspended solids concentration, excessive plant flows, high chemical concentrations, or exposure to very cold temperatures, be prepared for the problems discussed in this section.

1. High suspended solids concentrations will cause a filter to plug up fast, thus requring very frequent filter backwashes. This will result in high recycle flow rates through the plant and eventually the filters. This problem may be eliminated or reduced by having adequate spent backwash storage capacity or by having a "closed" filter system that will allow for clarification and reuse of spent backwash water for subsequent backwashes.
2. If no backwash storage or "closed" system is provided, hydraulic surcharge (overload) on the upstream side of the filters will result. Provisions must be made for filter bypass and/or storage. If bypass is the only alternative, you should anticipate increased chlorine demands at the chlorine injection point as a result of the increase in unfiltered suspended material. Adjust the chlorine dosage to compensate for the greater demands.
3. By allowing suspended material to bypass the filters and enter the chlorine contact tanks, more frequent cleaning of these tanks will be required.
4. If higher than normal plant flows can be anticipated (rain), it would be a good idea to operate the filter holding tank/wet well at a lower water level to provide for additional water storage. This action will reduce the surcharge possibility on the upstream side of the filters. This preventive action should also be used if a filter must be taken out of service for repairs or inspection.
5. If liquid alum is used and it is exposed to cold temperatures, the liquid alum will start to crystallize and the delivery of alum to the filter influent flow will be seriously impaired. If climatic conditions of this type are common in your area, consider storing the alum in an enclosed, warm space.
6. If chemical feed pump check valves or anti-siphon devices fail, large quantities of chemical will be drawn into the filters. This will result in short filter-run times due to increased differential pressure across the filter when a polymer is the chemical involved. When excessive alum concentrations are involved, the alum will pass through the filter media and filter effluent turbidity and suspended solids values will increase due to the alum breakthrough.
7. Filter flow and differential pressure valves may be sensed by differential pressure cells. These cells are water-activated and are fed through small-diameter piping. During periods of extremely cold weather these cells could freeze and prevent proper functioning of the filter and control instruments. Heavy insulation and/or heat tape will prevent the water in the cell piping from freezing.

4.421 Abnormal Operation

Efficient filter operation is essential if your final effluent quality is to comply with the waste discharge requirements established for your plant. Table 23.2 lists a few of the more common filter operational problems and suggestions on how to correct them.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 334.

4.4K What happens when large quantities of alum or polymer accidentally reach the filter?

4.4L What precautions should be taken in regions where freezing temperatures occur?

4.4M What could cause high operating filter differential pressures?

4.43 Maintenance

A comprehensive preventive maintenance program is an essential part of plant operations. Good maintenance will insure longer and better equipment performance. The following may be used as a guideline in performing the required maintenance on the pressure filter system.

A filtration system performance test should be done monthly. This test will enable you to evaluate and determine if the pumps, valves, filters, and control instruments are functioning properly. If they are not, the proper corrective action must be taken. A sample performance test form for three filters is shown in Figure 4.35.

Filter media and interior vessel surfaces should be inspected quarterly. The filter should be backwashed just prior to the inspection. Some of the items to look for are:

1. Is the media surface fairly flat and level? If not, the surface wash time should be reduced.
2. Are there mudball formations on or in the media? If so, an increased surface wash time in conjunction with a lower backwash rate should bring the media back to a clean condition.
3. Are very small quantities of mid-filter media particles visible on the top layer media surface? This condition is normal (refer to Section 4.413, Filters, page 322).
4. Do the surface wash arms rotate freely and in the proper direction? If not, the trouble could be a defective central bearing and tee. Are any nozzles plugged? If so, they must be cleaned.

CAUTION: Wear goggles when observing the operation of the surface wash arms. The velocity of water produced from the wash arms is great and will kick up surface media.

TABLE 4.2 ABNORMAL FILTER OPERATION

ABNORMAL CONDITION	POSSIBLE CAUSE	OPERATOR RESPONSE
PUMPS Do not meet pumping requirements.	Insufficient motor speed.	Install higher rpm motors.
	Pump impeller improperly set in bowl of pump.	Set impeller as per manufacturer's instructions.
	Excessive filter-system head losses.	Air in filter system. Analyze problem and take corrective action such as install higher rpm motors, redesign pump station, redesign force main, redesign orifice plates.
	Broken pump shaft.	Replace.
FILTERS (GENERAL) High operating filter differential pressure.	Filled with suspended material.	Backwash filters at least once every 24 hours.
	Excessive chemical feed "binding" media.	Evaluate and reduce dosage. Backwash filter.
Water discharges from pressure-relief valve.	Effluent valve(s) blocked or closed.	Investigate and correct valve problem
	Foreign object lodged between valve and seat.	Secure filter and clean valve seat.
Water discharges from air-relief valve.	Air pocket in underdrain system (most common after a backwash).	Secure filter for 2 to 3 minutes to allow vessel water level to stabilize, return filter to service. Adjust filter feed and backwash valves to open and close simultaneously to keep vessel full of water.
MEDIA Support media upset.	Air slug forced out by the backwash flow.	Install air relief valve on backwash influent line.
	Backwash flow pumped too suddenly.	Install flow-control valve for regulated flow rates.
	Backwash flow rate too high.	Install valve stops or limiting orifices.
Mud ball formation. Media surface cracks.	Inadequate surface wash time.	Increase surface wash time. Check to insure arms are operating.
Backwash water dirty at end of wash cycle.	Insufficient backwash time.	Increase time until clean water appears.
Media surface uneven after backwash.	Surface wash too long.	Decrease surface wash time.

5. Is there a small amount of foreign matter on the media surface (plastic, cigarette butts)? This condition is fairly normal and is most prevalent at the extreme effluent end of the backwash effluent header. The foreign matter is carried away by the backwash water during the next backwash cycle. If a large accumulation of foreign matter develops, the matter will have to be removed by manual means.

6. Inspect all interior metal surfaces to insure that the corrosion-inhibitive protective coating is in good condition. If not, prepare the affected surface and reapply the proper coating. An epoxy tar is frequently used for this purpose.

At least once monthly, the backwash rate should be observed to insure that the flow rate is correct as specified by the manufacturer's backwash rate-flow curve and that the backwash flow is allowed to enter the filter at a regulated rate. Observe the backwash effluent flow. The water should be clear at the end of the wash cycle. If it is not, an increase in the wash time is indicated.

The flow rates for the chemical feed pumps should be checked at least every two weeks. Corrective adjustments should be made to maintain the proper flow rates.

4.44 Safety

Safety precautions for sedimentation tanks and pumps set forth in Chapters 5, 14, and 15 *(OPERATION OF WASTEWATE TREATMENT PLANTS)* should be observed when operating and maintaining this equipment in the pressure filter system.

In addition, the following safety precautions should be observed:

1. Wear safety goggles and gloves when working with alum or polymers. Flush away any alum or polymer that comes in contact with your skin with cool water for a few minutes.
2. **Be very careful when walking in an area where polymer mixing takes place. When a polymer is wet, it is very slippery. Clean up polymer with a chlorine solution.**
3. When inspecting the interior of a filter vessel:
   a. Insure that all flow-control instruments are in the "OFF" position and that all valves are in the "MANUAL" or "OFF" position. Position all valves to prevent flow from entering the filter.
   b. Always ventilate vessel. Open two manway covers. Install and start an exhaust blower in one manway to provide fresh air circulation before entering the filter.
   c. Check vessel atmosphere for toxic gases (hydrogen sulfide), explosive conditions (Lower Explosive Limit), and sufficient oxygen.
   d. Entering a filter vessel is a three person operation. Two must be outside the vessel whenever one person is inside.
   e. Wear a hardhat when working inside a filter or around the filter vessel piping to protect your head from injury.

4.45 Review of Plans and Specifications

As an operator you can be very helpful to design engineers in pointing out some design features that would make your job easier. This section attempts to point out some of the items that you should look for when reviewing plans and specifications for expansion of existing facilities or construction of new pressure filter systems.

1. The variable hydraulic and suspended solids load in secondary effluents must be considered in the design to avoid short filter runs and excessive backwash-water requirements.
2. A filter that allows penetration of suspended solids (a coarse-to-fine filtration system) is essential to obtain reasonable filter run lengths. The filter media on the influent side should be at least 1 to 1.2 mm in diameter.
3. Auxiliary agitation of the media is essential to proper backwashing. Surface washers should be installed.

DATE: 7-21-87 BY: REDNER & KETTLE

VALENCIA WRP FILTER AND FILTER FEED PERFORMANCE TESTS

Test	PUMPS RUNNING			Filters on			Discharge Through Filters, GPM				Holding Tank Level	Pressure at Pump Discharge	Filter Differential Pressure			FILTER EFFLUENT FLOW CONTROL VALVE, % OPEN		
#	1	2	3	1	2	3	1	2	3	TOTAL	FEET	PSI	1	2	3	1	2	3
1	on	off	off	on	off	off	1400			1400	7.8	1.5	6.5			100	0	0
2	off	on	off	on	off	off	1100			1100	8.3	3.0	8.3			100	0	0
3	off	off	on	on	off	off	970			970	8.5	3.5	9.5			100	0	0
4	on	on	off	on	on	off	850	1400		2250	8.5	—	9.0	5.0		100	100	0
5	on	on	off	on	on	on	725	1224	1000	2950	8.5	5.0	8.5	5.0	5.0	100	100	100
6	on	off	on	on	on	on	700	1200	1000	2900	8.5	5.2	8.5	5.0	5.0	100	100	100
7	off	off	on	on	on	on	625	1075	925	2625	8.5	3.0	8.5	5.5	5.5	100	100	100
8	on	on	on	on	on	on	900	1275	1150	3325	7.7	8.0	9.5	6.0	6.0	100	100	100
9	on	off	off	off	off	on			1150	1150	7.7	3.0			7.0	0	0	100
10	on	off	off	off	on	off		1300		1300	7.9	3.0		6.5		0	100	0
11	on	off	off	on	off	off	975			975	8.0	3.2	10.0			100	0	0

NOTE: The filter effluent flow control valve should be 100% open during the monthly test.

REMARKS:

Fig. 4.35 Filtration system performance test chart

4. The effect of recycling used backwash water through the plant on the filtration rate and filter operation must be considered in predicting peak loads on the filters and resulting run lengths.
5. The filtration rate and head loss should be selected to achieve a minimum filter run length of 6 to 8 hours during peak-load conditions. This requirement will mean an average filter run length of 24 hours. Estimates of head loss development and filtrate quality should be based on pilot-scale observations of the proposed facility conducted at the treatment plant before the full-scale facility is designed.
6. Manways should be sized large enough to allow operators and equipment ease of entering and leaving the filter.
7. A media core sample port(s) should be provided to allow evaluation of the entire media depth.
8. Ladders and walkways should be provided to allow easy access to vessels, pipes, and valves.
9. Filter-flow charts should be provided to aid in monitoring filter performance.

4.46 Acknowledgments

1. County Sanitation Districts of Los Angeles, Valencia Water Reclamation Plant.
2. Mr. Jerry Schmitz, Draftsman, County Sanitation Districts of Los Angeles.

4.5 ADDITIONAL READING

1. *WASTEWATER FILTRATION DESIGN CONSIDERATIONS*, EPA Technology Transfer Seminar Publication, July 1974, U.S. Environmental Protection Agency, Center for Environmental Research Information (CERI), 26 West St. Clair Street, Cincinnati, Ohio 45268.
2. *PROCESS DESIGN MANUAL FOR SUSPENDED SOLIDS REMOVAL*, Technology Transfer, U.S. Environmental Protection Agency, Center for Environmental Research Information (CERI), 26 West St. Clair Street, Cincinnati, Ohio 45268.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 334.

4.4N What safety precautions should be taken when working with alum or polymers?

4.4O How frequently should a filter system performance test be conducted?

4.4P What caution should be exercised when observing the operation of the surface wash arms?

END OF LESSON 4 OF 4 LESSONS
ON
SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

DISCUSSION AND REVIEW QUESTIONS

(Lesson 4 of 4 Lessons)

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 3.

19. How are floatable and settleable solids removed from a holding tank?
20. How would you attempt to control corrosion of the interior surfaces of a pressure-filter vessel?
21. During what time of the day should the filters be backwashed?
22. What is the impact on downstream treatment processes if suspended solids get past the filtration system?

PLEASE WORK THE OBJECTIVE TEST NEXT.

SUGGESTED ANSWERS

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

Answers to questions on page 273.

4.0A NPDES stands for National Pollutant Discharge Elimination System.

4.0B Some locations have stringent discharge requirements because more and more wastes are being discharged into the receiving waters and increasing demands are being placed on the waters by water users.

4.0C Solids can be removed from secondary effluents by the addition of chemicals to cause coagulation and sedimentation, microscreens and gravity and pressure filters.

Answers to questions on page 276.

4.1A Chemicals may be added to reduce emergency problems such as those created by sludge bulking in the secondary clarifier, upstream equipment failure, accidental spills entering the plant, and seasonal overloads. Chlorine is the most common chemical used for disinfection.

4.1B When adding chemicals upstream from a biological treatment process, be sure that the chemical or its concentration is not toxic to the organisms treating the wastewater in the biological process.

Answers to questions on page 276.

4.1C The four most common chemicals added to improve settling are alum, ferric chloride, lime and polyelectrolytes (polymers).

4.1D Alum should be kept dry to prevent it from caking into a solid lump.

4.1E All mechanical equipment, such as conveyors, should be run until well-cleaned of all alum before shutting down because the alum can harden and jam the equipment.

Answers to questions on page 277.

4.1F Safety precautions required for handling ferric chloride in concentrated forms should be the same as those for acids. Wear protective clothing, face shields and gloves. Flush off all splashes on clothing and skin immediately.

4.1G Rubber or flexible piping with easy access and short runs will permit cleaning by squeezing the walls and washing out the broken scale. Solid piping that is plugged by scale usually requires replacement.

4.1H Clean up polyelectrolyte spills immediately. Polyelectrolytes will create an extremely slippery surface when wet.

4.1I Polyelectrolyte spills can be cleaned up by using chlorine. To clean up a spill, neutralize the polyelectrolyte with either salt (NaCl), liquid bleach or HTH powder.

Answers to questions on page 278.

4.1J Chemical solutions are prepared for feeding by mixing known amounts of chemicals and water together using a mechanical mixer. The resulting solution is stored in a day tank (holding tank) from which it is metered out at the proper dosage into the water being treated.

4.1K Common types of chemical feeders or metering equipment include:

1. Positive displacement pumps such as the piston pump, diaphragm pump, gear pump and progressive cavity pump;
2. Screw feeder;
3. Vibrating trough;
4. Rotary feeder; and
5. Belt-type gravimetric feeder.

Answers to questions on page 286.

4.1L Items that should be considered when selecting a chemical feeder include:

1. Total operating range.
2. Accuracy.
3. Repeatability.
4. Resistance to corrosion.
5. Dust control.
6. Availability of parts.
7. Safety.

4.1M The following information regarding a chemical feeder operation should be recorded:

1. Flows;
2. Characteristics of wastewater before and after treatment; and
3. Dosage and conditions of chemical treatment.

Answers to questions on page 291.

4.1N Factors that can cause a change in chemical dose requirements include:

1. Day of the week (weekdays or weekends);
2. Season of year (temperature and seasonal loadings); and
3. Year to year (changes resulting from industrial and population growth).

4.1O The most common method used to determine coagulation dosages is by running the jar test.

4.1P The jar test is an attempt to duplicate or simulate plant conditions by using laboratory equipment.

Answers to questions on page 292.

4.1Q Water quality indicators that should be monitored when operating a chemical treatment process include alkalinity, pH, temperature, turbidity and suspended solids.

4.1R Abnormal conditions that could be encountered in the water being treated when operating a chemical treatment process include high solids, high or low flows, and change in pH and temperature.

4.1S Problems that could occur when operating a chemical treatment process include no coagulation (solids not settling out) and foaming.

END OF ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 296.

4.2A Microstraining is a form of filtering used to clarify water by filtering out microscopic or very small suspended solids.

4.2B Microfabric is usually made of stainless steel wire, polyester, nylon cloth or plastic.

Answers to questions on page 297.

4.2C Major components of a typical microscreen include drum, microfabric, water spray system, solids waste hopper, drum drive units, ultraviolet lights, structure and bypass weir.

4.2D Ultraviolet lights are used to reduce biological growths on the microfabric. These growths can survive the water spray cleaning and will eventually clog the fabric.

Answers to questions on page 297.

4.2E Before starting a microscreen unit, inspect the electrical installation to be sure the controls are properly covered, fuses properly sized, and proper safety lock outs have been installed.

4.2F Items that should be included in the log of the operation of a microscreen include:

1. Hours of operation,
2. Volume of water processed, gallons or cubic meters,
3. Rate of application, gpd or cu m/day,
4. Applied suspended solids and BOD, lbs or kg/day,
5. Effluent suspended solids and BOD, lbs or kg/day,
6. Percent removal of suspended solids and BOD, %,
7. Chemicals added, pounds or kilograms,
8. Head loss through screen, inches or centimeters,
9. Maintenance performed on the unit, and
10. Remarks of special observations.

Answers to questions on page 299.

4.2G Abnormal conditions that could be encountered when operating a microscreen include:

1. High or low flows;
2. High solids loadings;
3. High or low pH values; and
4. High concentrations of oil and grease.

4.2H Problems caused by high or low pH levels include:

1. A high pH may result in the buildup of mineral deposits that will plug the fabric holes.
2. A rapid pH change may upset upstream treatment processes, thus increasing solids loadings.
3. A low pH may result in the corrosion of metal, especially the microfabric.

END OF ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 300.

4.3A A gravity filter should be cleaned when (1) the pressure drop (head loss) across the bed becomes so great that the flow is reduced, or (2) increased solids are observed in the effluent.

4.3B Most filters operate on a batch basis whereby the filter operates continuously until its capacity to remove solids is reached. At this time it is completely removed from service and cleaned.

Answers to questions on page 301.

4.3C Meanings of the following terms are:

1. Downflow. Water flows down through the bed.
2. Static bed. Bed does not move or expand while water is being filtered.

4.3D

1. In surface straining, the filter is designed to remove the solids at the very top of the media.
2. Depth filtration is designed to pull the solids deep into the media, thereby capturing the solids within as well as on the surface of the media.

Answers to questions on page 308.

4.3E Materials used for filter media include silica sand, antracite coal, garnet or ilmenite. Garnet and ilmenite are commonly used in multi-media beds.

4.3F If the filter media is not thoroughly cleaned during each backwashing, a buildup of solids will occur. The end result of incomplete cleaning is the formation of mudballs within the bed.

4.3G If nonfiltered water is supplied to the backwash system, clogging of the underdrain system may occur.

4.3H Used backwash water holding tanks are needed to prevent hydraulically overloading the treatment plant when backwash waters are returned to the headworks.

Answers to questions on page 310.

4.3I The head loss through the filter media is determined by measuring the water pressure above and below the filter media. When water flows through the media the pressure below the media will be less than the pressure above the media (when the pressure levels are measured or read at the same elevation).

4.3J Filter system alarms should be tested for proper functioning at least every 60 days.

Answers to questions on page 312.

4.3K A pre-start check should be conducted before starting filtering systems to prevent damage to the equipment and/or injury to personnel.

4.3L The purpose of the rate-control valve is to maintain the desired flow through the filter and prevent the backwash water from entering the filtered water during backwashing.

4.3M A filter should be backwashed after the capacity of the media to hold solids is well used up, but before solids break through into the effluent.

Answers to questions on page 313.

4.3N Abnormal operating conditions include:

1. High solids in applied water due to bulking sludge, rising sludge, or solids washout in the secondary clarifier.
2. Low suspended solids in applied water; however, solids pass through filter.
3. Loss of filter aid chemical feed.
4. High wet weather peak flows.
5. Low applied water flows.
6. High color loading.
7. High water temperature.
8. Low water temperature.
9. Air binding.
10. Negative pressure in filter.
11. High BOD and COD.
12. High coliform group bacteria levels.
13. Chlorine in applied water.
14. pH change in applied water.
15. High grease and oil in applied water.

4.3O To treat a high solids content in the water applied to a filter:

1. Run jar tests and adjust chemical dosage as needed;
2. Place more filters in service to prevent breakthrough; and
3. Prepare to backwash more frequently.

Answers to questions on page 315.

4.3P To determine if media are being lost, every three or four months measure and record the freeboard to the filter media surface. A small amount of media loss is normal, but an excessive amount (2 to 3 inches or 5 to 7 centimeters) indicates operational problems.

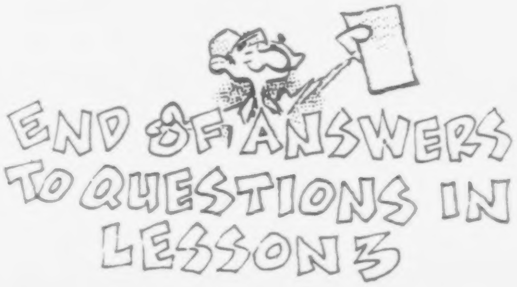
4.3Q Trees and shrubs should be kept away from uncovered filters because leaves will drop into the filter and they are very difficult to backwash out of the media.

Answers to questions on page 317.

4.3R The three main types of safety hazards around filtration systems are electrical, chemical and mechanical.

4.3S Filtration instrumentation should measure and record applied flows, backwash flows, head loss, and water quality before and after filtration.

4.3T Install all read-out meters, charts and gages of instruments in a convenient and centralized location.



Answers to questions on page 318.

4.4A The purpose of the inert-media pressure filter is to remove suspended solids and turbidity from secondary effluents to meet waste discharge requirements established by NPDES permits.

4.4B Chemicals commonly used with the filtration process are polymers and/or alum. The chemicals are used as coagulants for the solids and turbidity to aid in their removal by filtration.

4.4C Major components of a pressure filtration system include:

1. A holding tank or wet well;
2. Filter feed pumps;
3. Chemical coagulant feed pump system;
4. Filters;
5. Filter backwash wet well;
6. Filter backwash pumps; and
7. Decant tank.

Answers to questions on page 322.

4.4D The purpose of the holding tank is to store water and to allow additional settling of the suspended solids before the water is applied to the filter.

4.4E Alum is used for *COAGULATION* while polymers are used for *FLOCCULATION*.

4.4F **Known** **Unknown**

Polymer Conc., lb/gal = 0.6 lbs/gal

Polymer Pump, gpm = 0.15 gpm

Flow to Filter, gpm = 5,000 gpm

Polymer Dose, mg/*L*

ENGLISH

Calculate polymer dose, mg/*L*.

$$\text{Dose, mg}/L = \frac{\text{Flow, gal/min} \times \text{Conc., lbs polymer/gal}}{\text{Flow, gal/min} \times 8.34 \text{ lbs water/gal}}$$

$$= \frac{0.15 \text{ gal/min} \times 0.6 \text{ lbs polymer/gal}}{5{,}000 \text{ gal/min} \times 8.34 \text{ lbs/gal}}$$

$$= \frac{0.09 \text{ lbs polymer}}{41{,}700 \text{ lbs water}} \times \frac{1{,}000{,}000}{1 \text{ M}}$$

$$= 2.2 \text{ mg}/L$$

METRIC

$$\text{Dose, mg}/L = \frac{\text{Flow, } L\text{/sec} \times \text{Conc., gm polymer}/L \times 1{,}000 \text{ mg/gm}}{\text{Flow, } L\text{/sec}}$$

$$= \frac{0.0095\ L\text{/sec} \times 72 \text{ gm polymer}/L \times 1{,}000 \text{ mg/gm}}{315\ L \text{ water/sec}}$$

$$= 2.2 \text{ mg}/L$$

Answers to questions on page 327.

4.4G Major components of pressure filters include:

1. Vessels;
2. Interior piping;
3. Underdrain gravel (supporting media);
4. Inert media; and
5. Flow controls.

4.4H Water from the surface arms initially breaks up the mat of suspended material on the media surface.

4.4I The water used to backwash the filter comes from the chlorine contact tank (filtered and chlorinated) to the backwash wet well before it is used for backwashing.

4.4J The decant tank receives the backwash water from the filters. The backwash water is allowed to settle and the clarified effluent is recycled to the filters. The settled material is collected and discharged to the solids handling facility.

Answers to questions on page 327.

4.4K When a large quantity of polymer reaches a filter, short filter-run times will result due to increased differential pressure across the filter. When excessive alum concentrations are involved, the alum will pass through the filter media and filter effluent turbidity and suspended solids will increase due to alum breakthrough.

4.4L In areas where freezing temperatures occur, heavy insulation and/or heat tape will prevent the water in the cell piping from freezing. Also liquid alum should be stored in an enclosed, warm space.

4.4M High operating differential pressures could occur if either (1) the media is filled with suspended material; and/or (2) excessive chemical feed is "binding" the media.

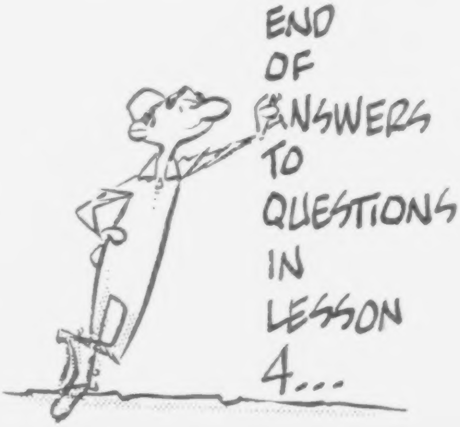
Answers to questions on page 330.

4.4N Safety precautions that should be taken when working with alum or polymers include:

1. Wear safety goggles and gloves when working with alum or polymers. Flush away any alum or polymer that comes in contact with your skin with cool water for a few minutes.
2. Be very careful when walking in an area where polymer mixing takes place. When a polymer is wet, it is very slippery.

4.4O Filter system performance tests should be conducted monthly.

4.4P Wear goggles when observing the operation of the surface wash arms.



OBJECTIVE TEST

Chapter 4. SOLIDS REMOVAL FROM SECONDARY EFFLUENTS

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. Ferric chloride is corrosive.
   1. True
   2. False
2. Safety precautions required for handling ferric chloride in concentrated forms should be the same as those for acids.
   1. True
   2. False
3. An overdose of a polyelectrolyte to a secondary effluent containing solids can be worse than no polyelectrolyte addition at all.
   1. True
   2. False
4. A progressive cavity pump may operate without feed material and not be damaged.
   1. True
   2. False
5. A coagulant may be used to precipitate phosphate as well as to remove solids from the water being treated.
   1. True
   2. False
6. Good housekeeping around chemical feeding systems is very important to good operations, but not important to safety.
   1. True
   2. False
7. If the microscreen drum is not rotating when the process water first enters the microscreen, the fabric may plug and be damaged.
   1. True
   2. False
8. Apply chlorine to control biological growths on the microfabric.
   1. True
   2. False
9. Rapid-sand filters may use either an upflow or a downflow backwashing process.
   1. True
   2. False
10. Downflow filters are designed to remove suspended solids by either the surface-straining method or the depth-filtration method.
    1. True
    2. False
11. The conventional single-media filter bed commonly used in potable water systems is generally unsatisfactory in removing solids found in wastewater because of plugging.
    1. True
    2. False
12. The finer, dense sand is placed over the coarse media (anthracite) in a dual-media filter.
    1. True
    2. False
13. Chlorine will not interfere with polyelectrolytes.
    1. True
    2. False
14. Dry filter media can be backwashed without any problems.
    1. True
    2. False
15. Alum is injected into the influent line of the filters downstream of the point of polymer injection.
    1. True
    2. False
16. Solids can be removed from secondary effluents by
    1. Activated sludge process.
    2. Addition of chemicals.
    3. Chlorination.
    4. Filtration.
    5. Microscreens.
17. Chemicals used to improve the settling of solids include
    1. ABS.
    2. Alum.
    3. Cations.
    4. Lime.
    5. Soda water.
18. Which of the following items should be inspected or checked before starting a chemical feeder?
    1. Direction of rotation of moving parts in motors
    2. Operation of control lights on control panel
    3. Operation of safety lock-out switches
    4. Proper voltage
    5. Size of overload protection
19. A jar test can be used to determine
    1. The most economical coagulation dosages.
    2. The number of jars of chemicals.
    3. The pH of a sample.
    4. The plant conditions by using laboratory equipment.
    5. What the clarity will probably be in the plant effluent.

20. Microstraining is capable of
    1. Disinfecting the effluent.
    2. Improving the effectiveness of the disinfectant.
    3. Removing soluble BOD.
    4. Reducing the coliform group organisms in the water being treated.
    5. Reducing the organic loading on the receiving waters.

21. Possible corrective actions to solve microscreen problems when treating high concentrations of oil and grease include
    1. Adding chemicals to improve oil and grease removals.
    2. Decreasing the drum rotation speed.
    3. Decreasing the water spray pressure.
    4. Placing fewer microscreens in service.
    5. Reducing oil and grease loadings at source.

22. Why should an empty filter not be filled through the inlet valve?
    1. Filling the backwash troughs in an empty filter places an unnecessary loading on the troughs.
    2. Question wrong. An empty filter should be filled through the inlet valve.
    3. This is a waste of production water.
    4. Untreated water will be discharged from the filter.
    5. Water falling onto the media will disturb the bed.

23. Indications of a disturbed or damaged filter underdrain include
    1. Boiling areas and quiet areas of the filter media during backwashing.
    2. Filter media in the effluent.
    3. Poor quality effluent suspended solids.
    4. Reduced effluent chlorine requirements.
    5. Reduction in effluent MPN.

24. Information that can be obtained from the head loss indicator on a rapid-sand filter includes
    1. Depth of filter media.
    2. Effectiveness of the backwash operation.
    3. Efficiency of BOD removal.
    4. Present condition of sand filter.
    5. Turbidity in the effluent.

25. Which of the following items should be included in your checklist for starting filtering systems?
    1. Backwash frequently to reduce head loss.
    2. Check motors for proper rotation.
    3. Fill tanks and piping and look for leaks.
    4. Inspect pumps and motors for excessive vibration.
    5. Inspect the total system for safety hazards.

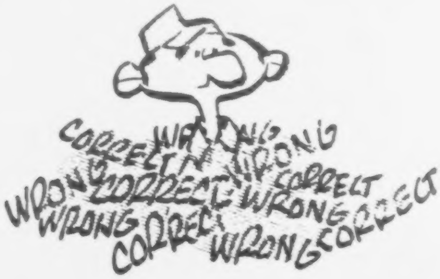
26. Which of the following items would you check if laboratory tests indicated high turbidity and suspended solids in the effluent of a filter?
    1. Check for excessive head loss.
    2. Determine filter aid dosages.
    3. Examine backwash cycle for complete wash.
    4. Inspect for damaged bed due to backwashing.
    5. Look for fluctuating flows that could cause breakthrough.

27. What conditions determine the backwash rate for a pressure filter?
    1. Largest media size
    2. Quality of the backwash water
    3. Settleability of solids in the secondary clarifier
    4. Suspended solids concentrations in the water applied to the filter.
    5. Warmest expected water temperature

28. Which of the following conditions can cause operational problems with a pressure filter?
    1. Excessive plant inflows
    2. High chemical concentrations
    3. High coliform MPNs
    4. High suspended solids concentrations
    5. Very cold temperatures

29. Factors that could upset the support media of a pressure filter include
    1. Air slug forced out by backwash flow.
    2. Backwash flow rate too high.
    3. High suspended solids concentrations in the water applied to the filter.
    4. Pumping backwash flow too suddenly.
    5. Surface wash too long.

30. Factors that should be considered when reviewing plans and specifications for new pressure filters include
    1. Filter media that allows penetration of suspended solids in order to obtain reasonable filter run lengths.
    2. Hoists to allow for inspection and maintenance of air headers.
    3. Ladders and walkways to allow easy access to vessels, pipes and valves.
    4. Manways sized large enough to allow operators and equipment ease of entering and leaving filters.
    5. Media core sample ports to evaluate entire depth of media.



END OF OBJECTIVE TEST

CHAPTER 5

PHOSPHORUS REMOVAL

by

John G. M. Gonzales

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OBJECTIVES

Chapter 5. PHOSPHORUS REMOVAL

Following completion of Chapter 5, you should be able to do the following:

1. Explain the need for phosphorus removal and describe some of the different systems used for this purpose at various treatment plants,
2. Place a phosphorous removal system into service,
3. Schedule and safely conduct operation and maintenance duties,
4. Sample influent and effluent, interpret lab results and make appropriate adjustments in the treatment process,
5. Recognize abnormal operating conditions, understand the cause, and take corrective action to ensure proper phosphorus removal,
6. Inspect a newly installed phosphorus removal facility to determine if installation has been proper, and
7. Review plans and specifications for a phosphorus removal system.

GLOSSARY

Chapter 5. PHOSPHORUS REMOVAL

AGGLOMERATION (a-GLOM-er-A-shun) AGGLOMERATION

The growing or coming together of small scattered particles into larger flocs or particles which settle rapidly. Also see FLOC.

CENTRATE CENTRATE

The water leaving a centrifuge after most of the solids have been removed.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, and draining or filtering.

ELECTRO-MAGNETIC FORCES ELECTRO-MAGNETIC FORCES

Forces resulting from electrical charges that either attract or repel particles. Particles with opposite charges are attracted to each other. For example, a particle with positive charges is attracted to a particle with negative charges. Particles with similar charges repel each other. A particle with positive charges is repelled by a particle with positive charges while a particle with negative charges is repelled by another particle with negative charges.

ENDOGENOUS (en-DODGE-en-us) ENDOGENOUS

A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles.

FLOC FLOC

Groups or clumps of bacteria and particles that have come together and formed a cluster.

POLYELECTROLYTE (POLY-electro-light) POLYELECTROLYTE

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."

POLYMER (POLY-mer) POLYMER

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."

PRECIPITATE (pre-SIP-i-tate) PRECIPITATE

To separate (a substance) out in solid form from a solution, as by the use of a reagent. The substance precipitated.

RECALCINATION (re-CAL-si-NAY-shun) RECALCINATION

A lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled through the water being treated to lower the pH.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

SLAKE SLAKE

To become mixed with water so that a true chemical reaction takes place, such as in the slaking of lime.

SLURRY (SLUR-e) SLURRY

A thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

CHAPTER 5. PHOSPHORUS REMOVAL

(Lesson 1 of 2 Lessons)

5.0 WHY IS PHOSPHORUS REMOVED FROM WASTEWATER?

5.00 Phosphorus as a Nutrient

Phosphorus provides a nutrient or food source for algae. Phosphorus combined with inorganic nitrogen poses serious pollution threats to receiving waters because of high algae growths which result from the presence of the two nutrients in water. Algae in water are considered unsightly and can cause tastes and odors in drinking water supplies. Dead and decaying algae can cause serious oxygen depletion problems in receiving streams which in turn can kill fish and other aquatic wildlife.

By removing phosphorus in the effluent of a wastewater treatment plant, the lake or river that the treatment plant discharges into will have one less nutrient that is essential for algae growth. This reduction in an essential nutrient reduces the growth of the algae.

5.01 Need for Phosphorus Removal

The U.S. Environmental Protection Agency and other water quality regulating agencies recognize the need to protect rivers and lakes from excessive growths of algae. Because of this, the agencies are requiring that wastewater treatment plants remove phosphorus in the effluent in order to protect the river or stream by eliminating a nutrient that can cause algae growth.

5.1 TYPES OF PHOSPHORUS REMOVAL SYSTEMS

Lime precipitation, luxury uptake, and filtration following aluminum sulfate flocculation are the most common types of phosphorus removal systems.

5.10 Lime Precipitation

When lime (calcium hydroxide ($Ca(OH)_2$) is mixed with effluent from a wastewater treatment plant in sufficient concentration to bring about high pH in the water, a chemical compound is formed which consists of phosphorus, calcium and the hydroxyl (OH^-) ion. This compound can be *FLOCCULATED*[1] or combined in such a way as to form heavier solids which can settle in a clarifier for phosphorus removal. A substantial amount of the lime reacts with the alkalinity of the wastewater to form a calcium carbonate *PRECIPITATE*[2] which also settles out with the phosphorus sludge. This calcium carbonate precipitate can be separated out of the sludge and *RECALCINED*[3] in a furnace to convert the calcium back to lime for reuse.

5.11 Luxury Uptake

Bacteria found in a normal activated sludge process use phosphorus within the make-up of the cell structure that forms the bacteria. When the bacteria are in a state of *ENDOGENOUS*[4] *RESPIRATION*[5] or are very hungry and need food and oxygen, they tend to absorb phosphorus quite freely. This process is called "luxury uptake" in which the bacteria take excess phosphorus into their bodies due to the stimulation of being placed in a proper environment containing food and oxygen. When these same bacteria are placed in an environment where there is no oxygen (anaerobic), the first element that is released by the bacteria as they almost begin to die is phosphorus. As the phosphorus is released, it can be drawn off and removed from the wastewater stream.

5.12 Aluminum Sulfate Flocculation and Precipitation (Sedimentation)

Aluminum sulfate (alum) in combination with wastewater also can flocculate phosphorus in much the same way as lime precipitation. The flocculation that happens with aluminum sulfate addition is the formation of aluminum phosphate particles that attach themselves to one another and become heavy and settle to the bottom of a clarifier. The aluminum sulfate and phosphorus mixture can then be withdrawn, thereby removing the phosphate or phosphorus from the wastewater flow. This alum *FLOC*[6] is difficult to settle out in a clarifier. Therefore, a sand or mixed-media filter is usually placed after the clarifier to remove the remaining floc.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 362.

5.0A Why is phosphorus removed from wastewater?

5.1A List the three major types of systems used to remove phosphorus from wastewater.

---

[1] *Flocculation (FLOCK-you-LAY-shun). The gathering together of fine particles to form larger particles.*

[2] *Precipitate (pre-SIP-i-tate). To separate (a substance) out in solid form from a solution, as by the use of a reagent. The substance precipitated.*

[3] *Recalcination (re-CAL-si-NAY-shun). A lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).*

[4] *Endogenous (en-DODGE-en-us). A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.*

[5] *Respiration. The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.*

[6] *Floc. Groups or clumps of bacteria and particles that have come together and formed a cluster.*

5.2 LIME PRECIPITATION

5.20 How the Lime Precipitation Process Removes Phosphorus

There are three general physical or chemical reactions which take place during lime precipitation for phosphorus removal (Fig. 5.1).

1. *COAGULATION.*[7] When chemicals are added to wastewater, the result may be a reduction in the *ELECTRO-MAGNETIC FORCES*[8] which tend to keep suspended particles apart. After chemical addition, the electrical charge on the particles is altered so that the suspended particles containing phosphorus, tend to come together rather than remain apart.
2. Flocculation. Flocculation occurs after coagulation and consists of the collection or agglomeration of the suspended material into larger particles. Gravity causes these larger particles to settle.
3. Sedimentation. As discussed in previous chapters on primary and secondary clarification methods, sedimentation is simply the settling of heavy suspended solid material in the wastewater due to gravity. The suspended solids which settle to the bottom of clarifiers can then be removed by pumping and other collection mechanisms.

5.21 Equipment Necessary for Lime Precipitation

Lime precipitation for phosphorus removal requires lime feeding systems, mixing and flocculation areas, chemical clarifiers for sedimentation and the proper pumps and piping for removal of lime phosphorus sludge. Other equipment includes facilities for pH adjustment of the effluent, recovery of the lime, and disposal of the phosphorus sludge. More specifically, the equipment needed for precipitation includes the following:

1. Lime Feed Equipment. Lime usually comes in a dry form (calcuim oxide (CaO)) and must be mixed with water to form a *SLURRY*[9] (calcium hydroxide ($Ca(OH)_2$)) in order to be fed to a wastewater treatment process to produce the required results.

   Calcium Oxide + Water → Calcium Hydroxide

   $$CaO + H_2O \rightarrow Ca(OH)_2$$

2. Mixing Chamber. A basin in which the lime slurry is blended with the wastewater as rapidly as possible with the use of a high-speed mixer called a "flash mixer." After this instant mixing of the lime slurry and wastewater, a slower mixing process called coagulation and flocculation follows to allow the formation of floc. This floc consists of suspended and colloidal matter, including the phosphorus precipitate.
3. Clarification Process. Clarification is used to allow the floc to settle out of the wastewater being treated. In order to settle lime phosphorus sludges, the velocity of the flowing wastewater must be slowed down sufficiently to allow for sedimentation. Because of the coagulation and flocculation process which produces heavier particles, a clarifier similar to a secondary sedimentation clarifier may be used in the process to settle lime phosphorus sludges.
4. Pumps and Piping for Lime Phosphorus Removal Process. After the lime phosphorus mixture has been settled on the bottom of the chemical clarifier, pipes and pumps must be used to transport the sludge to a thickening process for further dewatering and disposal.

5.22 Operation

5.220 Pre-Start-Up. Importance of Checking Chemical Strength

1. Lime (calcium hydroxide) is the most important ingredient in the phosphorus removal system. The calcium hydroxide strength must be checked in order to be sure that a high concentration of lime is available to form the chemical reaction necessary to precipitate phosphorus. Chemical strength is tested by determining the percentage of available calcium oxide in the dry lime that is being fed into the system. A concentration of at least 90 percent calcium oxide is needed to insure a highly reactive slurry for proper lime precipitation of phosphorus. See Chapter 16, "Laboratory Procedures and Chemistry," Section 16.47, "Lime Analysis," Volume II, for the testing procedures.
2. Lime Feeding Equipment. A routine check of lime feeding equipment is necessary several times during each work shift. Lime feeding is usually handled by slakers or equipment that mixes dry powdered lime with water to obtain a slurry. This slurry is then fed to the mixing basin for coagulation and flocculation of phosphorus. Since most dry lime has a certain amount of grit, rocks and sand in the mixture, a grit removal system associated with the *SLAKER*[10] or lime mixing feed system is important to prevent plugging and equipment wear. A rock-hard lime precipitate called calcium carbonate will form when lime combines with carbon dioxide. This rock-hard substance will attach itself to almost anything. Slaking mechanisms, piping and equipment must be kept free from a serious buildup of this calcium carbonate (limestone).
3. Pumps, Valves and Piping. The most serious problem faced in a lime system is the formation of limestone (calcium carbonate). All pumps, valves and piping must be regularly checked and cleaned to prevent a buildup of limestone scale which can cause plugging and malfunction. This applies to both the lime feed system which carries lime to the mixing chamber and to the chemical clarification unit. Similar maintenance procedures also apply to the lime slurry return system which takes settled lime and phosphorus sludge from the bottom of the clarifier and conveys the sludge to further dewatering and disposal processes.
4. Clarifier Mechanism. Lime clarifier mechanisms function the same way as secondary clarifiers. The clarifier sweeper arm should be able to move at a slow rate to collect the settled lime-phosphorus sludge at the bottom of the tank.

---

[7] *Coagulation (co-AGG-you-LAY-shun). The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining or filtering.*

[8] *Electro-Magnetic Forces. Forces resulting from electrical charges that either attract or repel particles. Particles with opposite charges are attracted to each other. For example, a particle with positive charges is attracted to a particle with negative charges. Particles with similar charges repel each other. A particle with positive charges is repelled by a particle with positive charges while a particle with negative charges is repelled by another particle with negative charges.*

[9] *Slurry (SLUR-e). A thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).*

[10] *Slake. To become mixed with water so that a true chemical reaction takes place, such as the slaking of lime.*

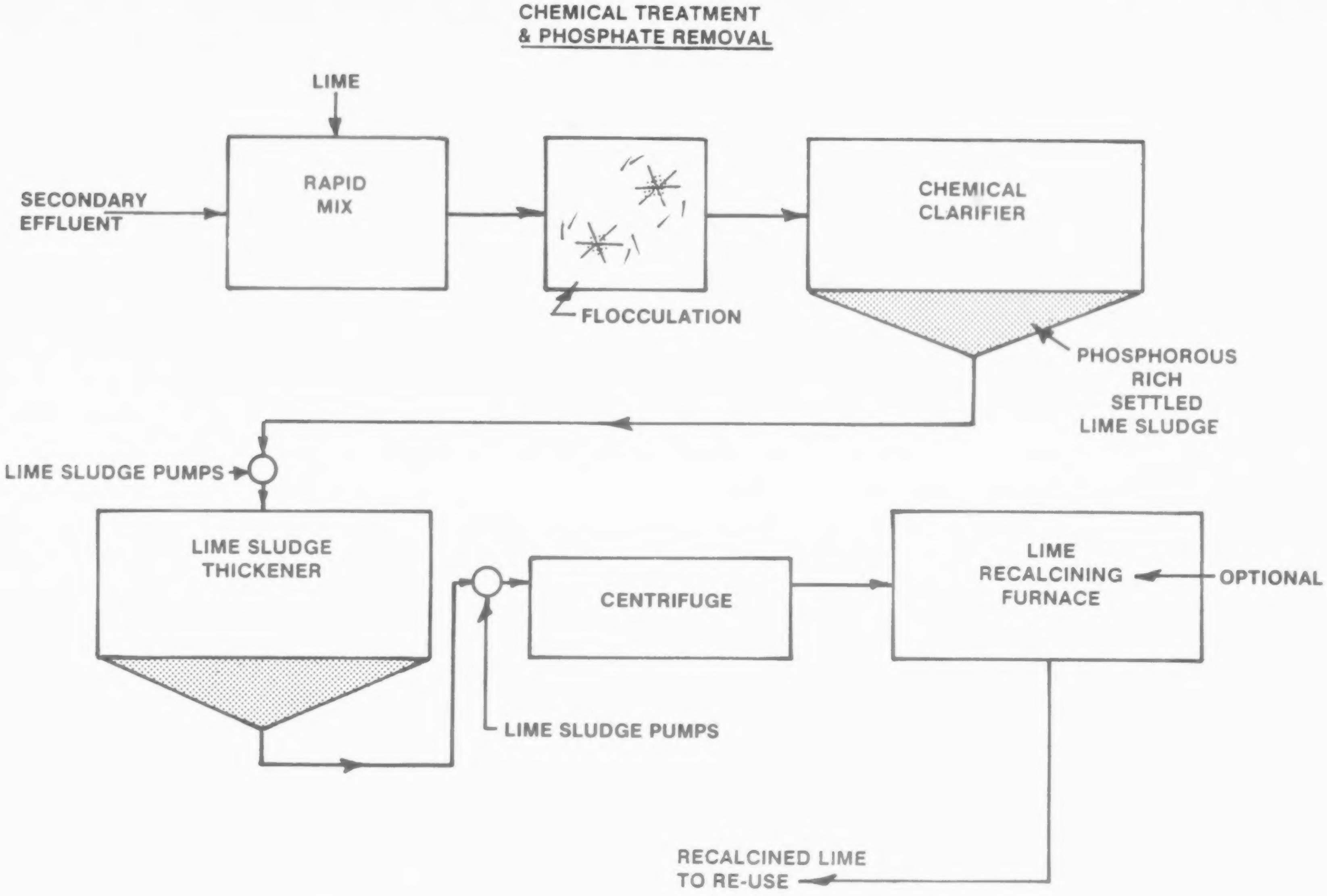
CHEMICAL TREATMENT
& PHOSPHATE REMOVAL
LIME
SECONDARY EFFLUENT
RAPID MIX
FLOCCULATION
CHEMICAL CLARIFIER
PHOSPHOROUS RICH SETTLED LIME SLUDGE
LIME SLUDGE PUMPS
LIME SLUDGE THICKENER
LIME SLUDGE PUMPS
CENTRIFUGE
LIME RECALCINING FURNACE
OPTIONAL
RECALCINED LIME TO RE-USE

Fig. 5.1 Lime precipitation process

5.221 Equipment Operating Procedures

1. Lime Feed for pH Control. pH adjustment for phosphorus removal means raising the pH to a very highly alkaline state (pH of 11 or higher) so that phosphorus and calcium hydroxide bond together forming a heavier substance that will settle out in a clarification process. Adding lime (calcium hydroxide) to the wastewater being treated will produce a high enough pH to allow the formation of this lime-phosphorus precipitate. The pH must be maintained above 11.0 in order to achieve the highest possible phosphorus removal using the lime clarification process.

   The lime-slurry-feeding system must be periodically checked for proper operation. Most lime-feed systems have automatic pH controllers that make this adjustment for you. The lime-feed system must be cleaned and maintained so it accurately measures out the quantity of lime necessary to adjust the pH to the proper level.

2. Clarification and Settling Process. After mixing, flocculation and coagulation, the lime-phosphorus precipitate is ready for settling in a clarification tank. The hydraulic loading rates must be adjusted to prevent short-circuiting or hydraulic washout of the floc prior to its complete settling to the bottom of the clarifier. A well operated chemical clarifier will be very clear and you should be able to see down into the clarifier at least 10 feet (3 m).

3. Pumping and Disposal of Lime Precipitate. Once the lime precipitate containing phosphorus is removed from the wastewater stream, it is important not to allow the same phosphorus to be recycled back through the treatment plant. Two methods of disposal are commonly used. In the first method, centrifugation of the lime mud removes the phosphorus from it. The remaining lime sludge can be further processed to recover the lime. In the second method, the phosphorus-lime sludge is simply pumped to an appropriate disposal site.

   When pumping lime precipitate from the clarifiers, the operator must adjust pumping rates so that all of the lime sludge is removed. Without proper pump regulation and adequate pumping times, heavy accumulations of lime could build up within the clarifier. Poor pump regulation could also lead to the pumping of only a very thin slurry composed mainly of water and little lime sludge to the disposal facilities.

5.222 Placing Lime Precipitation for Phosphorus Removal into Operation

1. Flow Rate into Chemical Clarifier. The operator should check the design criteria for the chemical clarifier to be certain that the overflow rates (weir loading rates and hydraulic loading rates) are not exceeded when starting up the chemical clarifier. The clarifier operates best at or below the overflow rate that was designed into the facility.

2. pH Adjustment in Flash-mix Basin. Check the pH adjustment in the rapid mix basin to be certain that the pH of the combined wastewater and lime slurry is 11 or above. If pH falls below 11, phosphorus removal efficiencies could be reduced. Measuring the pH on a regular and routine basis will provide a double check for the operator on the automatic pH adjustment and recording mechanism installed in the rapid mix basin area.

3. Turbidity and Phosphate Measurement of Clarifier Effluent. Along with phosphorus removal, a chemical clarifier is capable of removing turbidity from the secondary effluent at a wastewater treatment plant. The operator should check the removal efficiency of turbidity through the chemical clarifier as well as checking for efficiency levels for phosphorus removal. This is done along with calculations in the laboratory to determine the total phosphorus remaining in the effluent of the chemical clarifier compared to phosphorus levels in the effluent of the secondary portion of the treatment plant.

4. Pumping of Precipitated Lime Sludge for Disposal and for Lime Phosphate Separation. Some treatment plants use sludge drying beds to dry the lime sludge prior to final disposal by landfilling or other means. Other treatment plants recover as much of the lime as possible for reuse. These treatment plants must use two centrifuges. By operating the first centrifuge at a low removal efficiency, most of the phosphorus sludge is discharged with the *CENTRATE*[11] while most of the calcium carbonate is removed from the centrifuge as a cake ready for the lime recovery process in a multiple hearth furnace. The centrate containing most of the phosphorus sludge is passed through the second centrifuge for separation of the phosphorus compounds as a cake. The centrate is usually returned to the primary sedimentation system and the dewatered phosphorus sludge (cake) goes to a landfill for ultimate disposal.

   The operator must be certain that pumping equipment is operating efficiently. If the lime sludge is to be dewatered, the operator must see that the percent concentration of solids remaining after the dewatering process will provide the most efficient lime recovery operation.

   The solids handling portion (Chapter 22) of this manual discusses thickening and centrifugation processes in more depth. This chapter is very closely related to solids handling and you will need to understand the solids handling chapter thoroughly before you can reach a thorough working knowledge of the phosphorus removal system using lime precipitation.

5.223 Daily Operation

1. Routine pH Monitoring to Check Automatic Feed. As previously indicated, pH must be maintained about 11 in order to efficiently operate the phosphorus removal system. Routine checking with a pH meter will assure the operator of correct pH levels in the chemical clarification process. Measurement will also serve to check the automatic feed system to be certain that the pH control is properly functioning in the automatic mode.

2. Routine Phosphate Test for Removal Efficiencies. The purpose of chemical clarification and lime precipitation of phosphorus is to remove phosphate compounds from secondary clarified wastewater treatment plant effluent. Daily tests for removal of phosphate compounds through the chemical clarification system are necessary to determine the precise pH setting that works best for the treatment plant and conditions of operation at the facility. The phosphate test results are also required by State regulatory agencies that monitor phosphate levels in the final effluent from the wastewater treatment facility.

3. Calcium Oxide Content of Lime Feed. Phosphorus removal from wastewater requires substantial amounts of calcium oxide to raise the pH level of the wastewater so that chemical bonding occurs. Calcium oxide purchased for this purpose should contain at least 90 percent available calcium

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[11] *Centrate. The water leaving a centrifuge after most of the solids have been removed.*

oxide. Consult Chapter 16 on laboratory testing procedures for methods used in calculating and testing for calcium oxide content (Section 16.47, "Lime Analysis").

4. Daily Maintenance of Pumps, Piping and Other Equipment to Prevent Lime Scale Plugging. Lime (calcium hydroxide) and carbon dioxide form what is known as limestone or calcium carbonate. Calcium carbonate is a very stubborn substance that sticks to all types of surfaces. This scaling ability of the calcium carbonate causes pumps, piping and other equipment to scale very readily and they must be cleaned to prevent plugging problems. Daily maintenance will ensure that pumps operate properly and that pipes do not become completely plugged. Hot water or steam is very effective in dislodging limestone buildup within pipes or pumps. The hot water makes the calcium carbonate scale (limestone) soft and readily available for chipping away or scouring to remove the scale.

5.224 Shutdown of Lime Clarification Operation

If the lime clarification system for phosphorus precipitation must be shut down, take the following steps in the order listed:

1. Shut off valve to clarifier basin stopping the secondary effluent flow into the chemical clarifier.
2. Shut down lime feed equipment.
3. Bypass chemical clarifier by opening proper valves beyond secondary clarifier.
4. Pump settled lime sludge from clarifier basin.
5. If necessary, pump liquid from chemical clarifier basin into *RECARBONATION*[12] basin to inspect empty clarifier and perform any repairs that are necessary.
6. Flush equipment and chemical lines with water.

5.225 Sampling and Analysis

1. Phosphorus Removal Efficiencies. The purpose of lime precipitation of phosphorus is to reduce the phosphorus level in the effluent of the wastewater treatment plant and as a nutrient source for the receiving waters. Daily phosphorus tests should be run on composite samples of chemical clarifier effluent and also secondary clarifier effluent to see a comparison of results for determining two factors:
   a. Does the treatment plant meet effluent discharge requirements for phosphorus?
   b. Is the chemical clarification lime precipitation process adequately performing at the efficiencies desired?

   Consult the chemical analysis portion of Chapter 16 of this training manual to understand the laboratory testing process used for phosphorus analysis and interpretation of results.

2. Calcium Oxide Content of Lime Feed. A calcium oxide content of at least 90 percent available calcium oxide is needed in dry lime (quick lime) to bring the pH of the secondary treated water up to at least 11.0. The operator should check the concentration of any lime purchased. Consult the laboratory analysis section (Section 16.47) of Chapter 16 in this training manual to determine how to run a calcium oxide test and interpret the results. These test results will insure the use of high-grade lime as well as inform the operator about the reliability of the supplier.

   Calcium oxide content is also very important for treatment plants who recalcine their own lime. If the calcium oxide content drops in the recalcined lime, it is most likely due to higher concentrations of phosphorus within the lime sludge. When higher concentrations of phosphorus are returned to the system, lime clarification of phosphorus precipitation becomes less efficient. If calcium oxide levels drop too low in recalcined lime (less than 70 percent oxide), the recalcined lime should be wasted or disposed of rather than reused within the system.

3. Jar Tests to Determine Flocculation Efficiency. An efficiently operated chemical clarification unit will allow for proper settling of as large and as heavy a floc as possible.

   JAR TESTS[13] enable the operator to determine what pH levels form the largest floc possible and allow the fastest settling of the floc formation. *POLYELECTROLYTES*[14] have been used with lime precipitation of phosphorus removal and are added after the fast-mix reaction. The jar tests are very good indicators of the concentration of *POLYMERS*[15] that produces optimum floc formation and sedimentation of the calcium hydroxide phosphate combination floc particles.

5.226 Operational Strategy

5.2260 Daily Operating Procedures. There are three main areas to check in the daily operation of a phosphorus-lime precipitation chemical-clarification unit:

1. Lime Feed System. The lime-feed system must be operated very efficiently. Be certain to check the automatic dry lime feed system, the mixing process of dry lime and water, the slurry transfer to the rapid-mix basin and the grit removal system to remove sand from the lime slurry.
2. Flash Mixing, Coagulation and Flocculation. After the lime has been fed into the secondary effluent flow stream, it is very important that the mixing time and chemical feed ratio (polymer and lime) be correct so that pH can be maintained above 11.0 and to promote formation and rapid settling of the largest possible floc.
3. Lime Clarification, Sedimentation and Sludge Removal. After the lime sludge removal process has entered the chemical clarification state, it is important for the operators to make sure that lime does not build up too heavily and that lime phosphorus sludges are pumped on a regular basis from the bottom of the clarifier. The lime sludge should be properly pumped and piped to the disposal area or the thickener process for further dewatering.

5.2261 Abnormal and Emergency Conditions

1. Changing Flow Conditions. During low flow conditions, check the automatic lime-feed system to be sure it has adjusted to the reduced flows. Excessive lime-feed rates

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[12] *Recarbonation (re-CAR-bun-NAY-shun). A process in which carbon dioxide is bubbled through the water being treated to lower the pH.*

[13] *See Chapter 23, Section 23.130, "Jar Test," for details on how to run a jar test.*

[14] *Polyelectrolyte (POLY-electro-light). A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."*

[15] *Polymer (POLY-mer). A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."*

into the clarifier waste the chemicals and increase the costs. If the automatic lime-feed system cannot be throttled down far enough, manual feed control is necessary.

High flows can pose a more serious problem to lime clarification processes. First, high flows may cause a lowering of pH if the lime-feed system is not properly pacing the flow by adding excess lime when the high flow conditions occur. Secondly, high flow can mean hydraulic overloading of chemical clarification units thereby causing a decrease in the efficiency of phosphorus removal in the clarification unit.

2. Factors Affecting Phosphorus Removal Efficiency

   a. Short-circuiting. Short-circuiting can be caused by too high a flow within the chemical clarification unit. A high flow will not allow adequate detention time. When short-circuiting occurs, the flocculated particles do not settle properly and are washed over the effluent weirs.

   b. Changes in pH. Fluctuating pH levels may have the effect of causing cloudy conditions in certain portions of the clarification tank. The most efficient manner in which to operate a chemical clarification unit is to maintain a constant pH above 11.0. When the pH drops below 11.0 for even a short period of time, floc for that flow may not be as large and a cloud of suspended particles may appear within the clarification unit.

   c. Solids Loading. Since most chemical clarification units for phosphorus precipitation follow a secondary clarifier, it is important that the secondary clarifier run as efficiently as possible. If solids are not settled properly within the secondary clarification unit causing high solids to appear in the chemical clarifier phosphorus precipitation units, then removal efficiencies for phosphorus will decrease. Under these conditions it will be more difficult to maintain a high pH in the clarifier and clarity will be impaired substantially.

   d. Small Straggler Floc. Usually a small floc will occur because of improper pH or because the polyelectrolyte being used is either at too high a dose or too low a dose for proper control of the flocculation process. The straggler floc will not settle as readily as the large floc and, therefore, efficiency in the phosphorus removal process may be drastically reduced.

   e. Storm Water. If substantial high flows result because of high storm water runoff into the sewer system, phosphorus removal efficiencies will be substantially reduced because of the short-circuiting due to lack of detention time within the clarification basin. Be sure to cut down valving if you suspect a high flow condition that has resulted from a storm condition. High flows through the chemical clarifier will cause settled floc to rise and will prevent sedimentation of the particles.

   f. Industrial Dischargers. Industrial dischargers who ignore discharge restrictions can cause serious problems for the chemical clarification unit. Discharge of toxic wastes can destroy secondary biological systems, thereby reducing the secondary clarification efficiency ahead of the phosphorus removal system.

   g. Plugged Pumps or Piping. Lime-phosphorus sludge must be pumped from the bottom of a chemical clarifier as it accumulates. If plugging problems occur because of a calcium carbonate buildup, they should be corrected immediately. If piping or pump problems are allowed to continue, they could result in an excess buildup of solids within the chemical clarifier and seriously reduce phosphorus removal efficiency.

   h. Lime Feed Equipment to Maintain Adequate Lime Supply. The most important phase of the chemical clarification process that requires close control is the lime-feed process. If there is a breakdown in the lime feed operation, phosphorus removal cannot take place. Lime feeding must be continuous and have an adequate feed supply program. The lime slakers or mixers should be regularly inspected. All piping should be examined and deposited scale chipped off the pipes. The lime feed should also be using a high concentration of calcium oxide.

   i. Operational Problems with Upstream or Downstream Treatment Processes. The most serious effect from an upstream treatment process on chemical clarification and phosphorus removal is an upset condition in the secondary treatment process of the treatment plant. The upset condition can cause a lowering of the pH, too many suspended solids in the chemical clarifier and a substantial problem for removal efficiencies for not only phosphorus but turbidity and suspended solids. The solids carryover from a secondary clarifier also interferes with any recalcining operation that may be used at the treatment plant if lime is reclaimed.

      Downstream treatment processes will usually include a recarbonation basin to bring the pH back to a neutral point. Carbon dioxide from the recalcining process is commonly used in the recarbonation basin. If the carbon dioxide feed is not adequate, a high pH will result in the remainder of the treatment plant. This condition may be in violation of the discharge permit for the treatment facility. Most states require a pH in the relatively neutral range before discharge to any body of water or even for land disposal. The operator should be sure that the recarbonation process is working properly and that an adequate supply of carbon dioxide is being fed to bring the pH back down to a range within the plant's effluent discharge permit requirements.

   j. Recarbonation for pH Control and Calcium Carbonate Recapture. Effluent from a high pH chemical clarifier used for phosphorus reduction will usually have a pH of at least 11. Use of carbon dioxide (CO_2) is the most common method of neutralizing the pH (bring the pH of the water down to almost 7). A by-product of the lowered pH is the formation of settleable calcium carbonate that can be recalcined for reuse in the lime treatment procedure. The process can be accomplished by either using a single or a two-stage recarbonation and settling process.

      Single-stage recarbonation as shown in Fig. 5.2 uses a process of adding carbon dioxide (CO_2) gas to the effluent from a chemical clarifier. The gas is bubbled into the effluent stream to allow calcium carbonate to form. As a by-product of the calcium carbonate formation, pH is reduced.

      The calcium carbonate precipitate formed is captured on filters which usually follow a chemical clarification process. The calcium carbonate captured on the filter media must be settled following a filter backwashing procedure.

Two-stage recarbonation and settling as shown in Fig. 5.3 is a more effective method to reduce wastewater pH and recapture calcium carbonate. Carbon dioxide gas is bubbled into a basin just after the chemical clarification process. However, unlike single-stage recarbonation, the calcium carbonate precipitate formed is allowed to settle in a basin or tank. The settled calcium carbonate is collected and

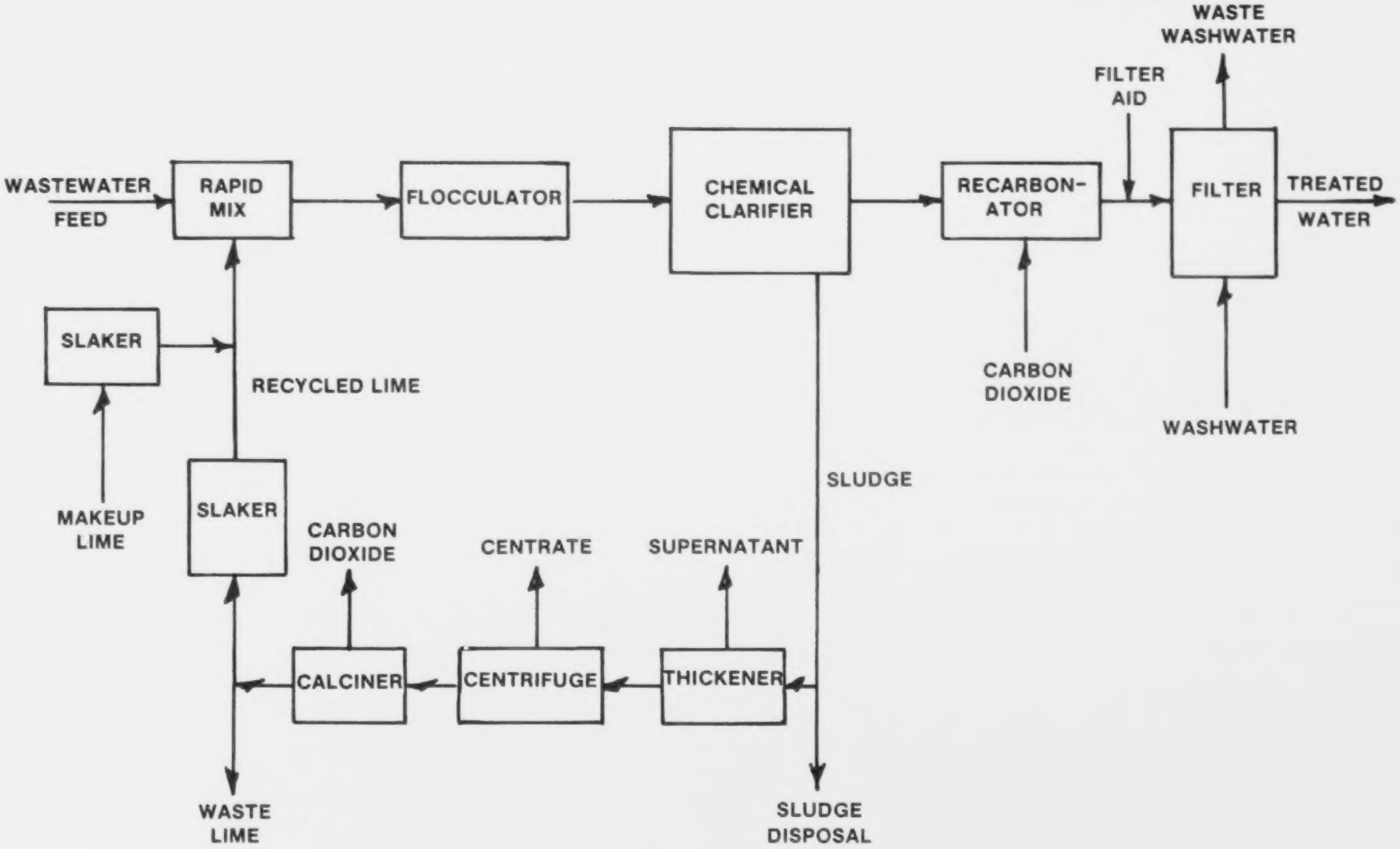
WASTE WASHWATER
FILTER AID
WASTEWATER FEED
RAPID MIX
FLOCCULATOR
CHEMICAL CLARIFIER
RECARBON-ATOR
FILTER
TREATED WATER
SLAKER
RECYCLED LIME
CARBON DIOXIDE
WASHWATER
SLUDGE
MAKEUP LIME
SLAKER
CARBON DIOXIDE
CENTRATE
SUPERNATANT
CALCINER
CENTRIFUGE
THICKENER
WASTE LIME
SLUDGE DISPOSAL

Fig. 5.2 Single-stage lime recarbonation process

(Source: Process Design Manual for Phosphorus Removal, EPA 625/1-76-001A)

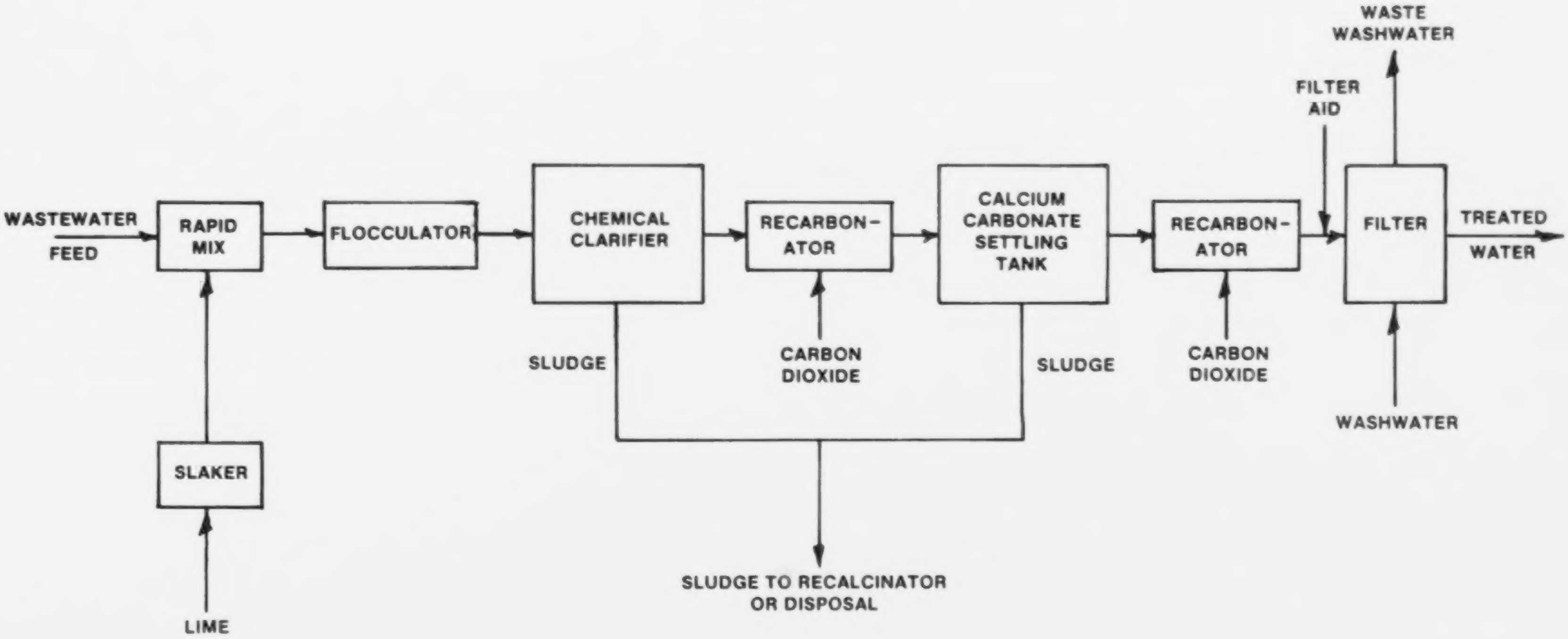
WASTE WASHWATER
FILTER AID
WASTEWATER FEED
RAPID MIX
FLOCCULATOR
CHEMICAL CLARIFIER
RECARBON-ATOR
CALCIUM CARBONATE SETTLING TANK
RECARBON-ATOR
FILTER
TREATED WATER
SLUDGE
CARBON DIOXIDE
SLUDGE
CARBON DIOXIDE
WASHWATER
SLAKER
SLUDGE TO RECALCINATOR OR DISPOSAL
LIME

Fig. 5.3 Two-stage lime recarbonation process

(Source: Process Design Manual for Phosphorus Removal, EPA 625/1-76-001A) pumped to dewatering and recalcination or hauled to a landfill. Carbon dioxide gas is again bubbled into the wastewater stream to further reduce the pH.

Usually pH is reduced to around 8.0 to 8.5 in first-stage recarbonation and further reduced to 7.0 in second-stage recarbonation. After second-stage recarbonation, the wastewater is treated by filtration. An additional advantage of two-stage recarbonation over single-stage recarbonation is the lower quantities of calcium carbonate that can plug filters that follow the recarbonation process.

The stack gases from the recalcination furnace usually are used as a source of carbon dioxide gas. Additional carbon dioxide may be required to be produced by an auxiliary burner or from commercially tanked carbon dioxide.

5.2262 Troubleshooting

The following are some of the important points to look for when operating a lime clarification system for removal of phosphorus. These points and guidelines are some of the many that operators should consider when operating the equipment for the phosphorus removal system.

1. Remove any debris from the bottom of the chemical clarification basins.
2. Make sure the sludge scraper mechanisms for chemical clarification units are operating in good condition before allowing any flow to enter the sedimentation basin.
3. A high torque level on the rotation of the clarifier drive mechanism provides a warning that the rotating collection arms of the chemical clarifier have a problem or that the unit is binding.
4. Pumps which operate at slower-than-normal feed rates or which will not pump are a strong indication that the pump or the sludge lines are plugged. Observation of pump pressure gages will indicate if a pump is not working properly.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 362.

5.2A What equipment is necessary for the removal of phosphorus by the lime precipitation process?

5.2B Why must the slaker or lime mix feed system have a grit removal system?

5.2C Daily operation of a lime precipitation process to remove phosphorus consists of what tasks?

5.2D Why are low flow conditions of concern for the lime precipitation process?

5.2E What factors affect phosphorus removal efficiency in the lime precipitation process?

5.23 Maintenance

1. Pumps and Seals. As indicated in previous sections, pumps are a very important and major part of any wastewater treatment facility. Pumps and seals must be kept properly maintained in order that the pumps can work and function at their peak efficiency without needing major repair over the period of use. Seals and packing must be kept in good condition so that the pump can run cool and efficient at all times. Lime is both caustic and abrasive and therefore can wear equipment at a rapid rate. Special attention must be paid to any pumps that handle lime sludges in order to be certain that plugging and excessive wear are not major problems in the pump operation.
2. Piping. Because of the tendency of lime to form scale, piping must be kept clean at all times. Lime builds up on the interior walls of pipes and can plug the pipes at a rapid rate. Flushing and scouring pipes are periodically necessary in order to ensure that the lime sludge is being moved to other parts of the treatment plant as expected.
3. Clarifier Mechanism. Since the clarifier rotating arm moves continuously, it is very important that the proper oil and grease be provided for lubrication. Be certain that the bearings are lubricated and that no obstructions cause jamming or excessive wear on the equipment. Be sure to check the manufacturer's recommendations for the operation of the clarifier mechanism. All internal parts must be sealed and preventive maintenance should ensure that lime and weather elements do not affect the operation of the working gears within the mechanism drive.
4. Lime Slaking Mechanism. The lime slaking mechanism must be kept in good operating order in order to provide the correct amount of lime slurry for the lime feed station. Grit must be removed from the slaker mechanism and the mixing arms must be kept free of excessive buildups of lime. Be sure to check the manufacturer's recommendation on slake temperature. Frequently inspect the water sprays used for condensing the steam and for dust control. The lime slaking mechanism should be cleaned frequently to prevent lime build-up.
5. Flash-mix Basin. Lime has a tendency to build up on the surface of the mixing paddles in a rapid-mixing chamber. Be sure that no excessive amounts of lime are allowed to gather on any mixing paddles. This could cause heavily weighted sides that set the mechanism off balance. The mixing paddles should be cleaned frequently to prevent lime buildup.
6. Automatic pH Control. The pH probe that helps the lime feed system work in automatic mode must be cleaned on a daily basis to ensure that a lime scale buildup does not cause false readings. The automatic recording station to control the pH must be calibrated periodically to ensure that the mechanism is functioning properly.
7. Ratio of New Lime to Recalcined or Reclaimed Lime. If the treatment plant has a recalcining furnace in which lime is reclaimed, be sure that the ratio of new lime to recalcined lime is adjusted so that the quality of lime fed to the mixing chamber is high enough to provide adequate pH control and phosphorus removal. This ratio is computed by using the known factors of calcium oxide content in both the recalcined or reclaimed lime and the new lime.

5.24 Safety

1. Lime is a Powerful Caustic Solution. Because lime has an extremely high pH, it is a very caustic solution and can cause eye irritation and skin irritation when it comes in contact with operators. Be very careful when using lime. Wear goggles and face masks to prevent the lime from entering eyes or lungs. If you are exposed to lime in either your eyes or parts of your body, be sure to rinse with water thoroughly and, in the case of severe burns, be certain to see a physician immediately. A mild solution of boric acid may be kept on hand to help flush eyes in case of a severe lime burn or exposure of the eyes to dry lime.
2. Polymers Can Cause Slick Surfaces. Many times a lime process uses polymers to help form colloidal particles of

lime and phosphorus to provide faster sedimentation in a lime clarification unit. These polymers, when wet, are extremely slippery. Be very careful when walking near surfaces that have been exposed to any kind of polyelectrolyte or polymer. Be sure to wash down any surfaces where polymers have been spilled and use guard railings on stairs or near concrete areas that may have polyelectrolytes on the surface.

5.25 Loading Guidelines

1. Typical Loading Rates. The typical loading rate for a chemical clarification unit is normally 800 gallons per day per square foot (32 cu m per day/sq m) of surface area to 1500 gallons per day per square foot (60 cu m per day/sq m) of surface area.
2. Hydraulic Loading Computation. In order to calculate the hydraulic loading rate for a lime clarification unit, the operator must know two things: (1) the flow into the lime clarification unit, and (2) the surface area of the clarifier. To calculate the hydraulic loading rate, divide the average gallons per day (cubic meters per day) of flow to the clarifier by the square feet (square meters) of surface area. This will give the overflow rate or hydraulic loading of the lime clarification unit.

$$\text{Hydraulic Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}}$$

or

$$\text{Hydraulic Loading, cu m/day/sq m} = \frac{\text{Flow, cu m/day}}{\text{Surface Area, sq m}}$$

3. Phosphate Loading Computation. Phosphate loading is normally designed as pounds per day (kilograms per day) of phosphorus to be treated. This loading can either be a total loading rate of phosphate into the lime clarification unit or it can be the phosphorus removed from the lime clarification unit. To calculate the phosphate loading, the operator needs to know: (1) the gallons per day (cubic meters per day) of flow entering the lime clarification system, (2) the milligrams per liter of phosphate in the secondary effluent, and (3) the milligrams per liter of phosphate in the chemical clarification effluent. In order to compute the *PHOSPHATE*[16] loading, use the following equations:

$$\text{Phosphate Loading, kg/day} = \text{Flow, MGD} \times \text{Phosphate, mg/}L \times 8.34\ \text{lbs/gal}$$

or

$$\text{Phosphate Loading, kg/day} = \text{Flow, } \frac{\text{cu m}}{\text{day}} \times \text{Phosphate, } \frac{\text{mg}}{L} \times \frac{1\ \text{kg}}{1{,}000{,}000\ \text{mg}} \times \frac{1000\ L}{1\ \text{cu m}}$$

To determine the efficiency of the phosphate removal process by lime clarification, use the following equations:

$$\text{Phosphate Removal Efficiency, \%} = \frac{\left(\text{Influent Phosphate, lbs/day} - \text{Effluent Phosphate, lbs/day}\right) \times 100\%}{\text{Influent Phosphate, lbs/day}}$$

or

$$\text{Phosphate Removal Efficiency, \%} = \frac{\left(\text{Influent Phosphate, kg/day} - \text{Effluent Phosphate, kg/day}\right) \times 100\%}{\text{Influent Phosphate, kg/day}}$$

or

$$\text{Phosphate Removal Efficiency, \%} = \frac{(\text{Infl. Phos., mg/}L - \text{Effl. Phos., mg/}L) \times 100\%}{\text{Infl. Phos., mg/}L}$$

5.26 Review of Plans and Specifications

In many instances, it is very beneficial to the design engineer, to the operator and to the facility for the operator to review the plans and specifications of an expanded treatment plant or new treatment facility prior to the completion of the plans and specifications. The design review helps the design engineer to know what details to look for to make operations easier and to anticipate problems that might otherwise require design modifications after construction is completed. Without the operator's assistance, modification might later be necessary because someone forgot or did not have the knowledge to recommend specific details for better operational control of the phosphorus removal process.

The following are some of the items that can be reviewed by the operators to aid the design engineer during the facility's design for phosphorus removal:

1. Abrasive nature of quick lime or powdered calcium hydroxide. Because of the abrasive nature of lime, it is important that large sweeping curves be used in any air transfer of dry lime. The large sweeping curves will not let the centrifugal force and velocity of the particles of lime eat through the interior of the pipe wall on the curves while transferring lime from the hauling vehicle to the storage bins.

2. Lime-water mixture causing steam. Because of the quick chemical reaction of lime with water, a great deal of heat is formed causing a certain amount of steam. This steam can cause the lime to clump up into large particles reducing the effectiveness of a lime storage bin and its feed mechanism. Because of the steam, clumping can cause bridging, and lime feeding into chemical slakers may be a severe problem. Provisions should be made for water sprays to control dust and to condense vapors so they will not rise into the storage bin.

3. Accessibility to piping for lime feed. Because of the ability of lime to build up on the surfaces of metal and other materials, it is important to be able to clean lime feed pipes. If a long distance exists between the lime mixing and slaking area and the rapid-mix basin, several manholes should be located within the pipe route to ensure easy access for cleaning.

4. Flexible piping arrangement. Because pumps and pipes plug up frequently in a lime sludge pump station, it is important that alternate piping and valving be provided so that lime sludge removal can continue while cleaning and repairs are made on the affected equipment.

5. Handling of dry lime from the unloading dock. The trucks hauling dry lime to storage bins at the treatment plant must have enough room to maneuver and park in the unloading area. Usually, the trucks have their own pneumatic exhaust system to transfer the lime from the truck to the storage bins. If the bins are taller than the truck, it is critical that the feed line first go straight up from the unloading vehicle. This will prevent lime from depositing on the bottom of the pipe with the air flowing over the top. This arrangement will allow much faster unloading time for the vehicles.

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[16] *Phosphate in these equations usually refers to total phosphate and includes orthophosphates, polyphosphates, and organic phosphorus. Both poly and organic forms of phosphorus must be converted to orthophosphate for measurement.*

6. Dust control. Because lime is extremely hazardous to human health, it is important that proper dust control be provided. Exhaust fans and lime filter bags must be provided to keep lime dust from spreading throughout the lime feeding building or into the operational area causing operators breathing problems and other unpleasant conditions.
7. Safety of lime bins. Because pneumatic feeding mechanisms are the most common devices for transferring lime to the storage bins, it is important that these bins be properly vented and that dust collectors be provided at each vent.

5.27 Additional Reading on Lime Precipitation for Phosphorus Removal

1. *HANDBOOK OF ADVANCED WASTEWATER TREATMENT*, Second Edition, Culp. R. G., Wesner, M., Culp, G. G., Van Nostrand Reinhold, New York City, N. Y., 1977. Obtain from Litton Educational Publishing, Inc., 7625 Empire Drive, Florence, Kentucky 41042. Price: $35.00.
2. *PROCESS DESIGN MANUAL FOR PHOSPHORUS REMOVAL*, EPA 625/1-76-001a, U. S. Environmental Protection Agency, Center for Environmental Research Information (CERI), 26 West St. Clair Street, Cincinnati, Ohio 45268, April 1976.
3. *WASTEWATER SYSTEMS ENGINEERING*, Parker, Homer, Prentice-Hall, 301 Sylvan Avenue, Englewood Cliffs, New Jersey 07632, 1975. Price: $33.95.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 362.

5.2F What is the purpose of the lime slaking mechanism?

5.2G What is recalcined lime?

5.2H Why might a lime process also use a polymer?

5.2I What forms of phosphorus are included in the total phosphate measurement?

5.2J What provisions can be made when a facility is designed to reduce problems that will arise when pumps or pipes become plugged with lime?

END OF LESSON 1 OF 2 LESSONS
ON
PHOSPHORUS REMOVAL

Please work the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. PHOSPHORUS REMOVAL

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. How is phosphorus removed from wastewaters by "luxury uptake?"
2. What is the most serious problem in a lime system and how can this problem be avoided or corrected?
3. Why would you perform a jar test when removing phosphorus by the lime precipitation process?
4. Why must lime be kept from gathering on the mixing paddles in the flash-mix basin?
5. List the safety hazards you might encounter when working with lime.

CHAPTER 5. PHOSPHORUS REMOVAL

(Lesson 2 of 2 Lessons)

5.3 LUXURY UPTAKE OF PHOSPHORUS

5.30 How the Luxury Uptake Process Works

5.300 Process Description (Fig. 5.4 and 5.5)

Luxury uptake of phosphorus is a biological treatment process whereby the bacteria usually found in the activated sludge treatment portion of the secondary wastewater treatment plant are withdrawn to an environment without oxygen (anaerobic). When the bacteria are faced with the situation of apparent death, the bacteria release phosphorus from their cell structure in large quantities. Phosphorus can then be removed and disposed of by using lime for settling similar to the previously discussed lime clarification process. After the bacteria have released their phosphorus, they are placed back into an ideal environment with oxygen and food. In this environment, since the bacteria are lacking in phosphorus in their cell structure, the first thing they take in is phosphorus. This phosphorus take-up is known as luxury uptake and is used in the process for biological removal of the phosphorus within the wastewater treatment facilities.

5.301 Wastewater Treatment Units Used

Luxury uptake of phosphorus is found at activated sludge treatment plants. The units used include the standard ones for an activated sludge plant plus a relatively deep detention basin where anaerobic conditions exist (see anaerobic phosphorus release tank in Figs. 5.4 and 5.5). Another unit commonly found in the luxury uptake and removal system is a lime clarification tank (clarifier) which is usually capable of treating 10 percent of the wastewater flow stream through the treatment facility. Return pumps and piping continue to move the activated sludge through an anaerobic state to a phosphorus release point and back to aeration for the luxury uptake process to begin all over.

5.302 Basic Principles of Operation

Because luxury uptake can only take place in a very controlled environment, the bacteria cannot be exposed to any condition which would prevent them from either taking up phosphorus into their cell structure or releasing the phosphorus at the proper time. The basic operation requires the operators to remove the activated sludge from the secondary clarifier and provide the proper detention time in an anaerobic tank for the release of the phosphorus trapped within the cell structure of the bacteria. The operator must closely regulate the time of the anaerobic condition. The bacteria should not be allowed to die. However, the length of time should be sufficient to remove as much of the phosphorus as possible. Return the activated sludge to an area of the aeration tank where sufficient oxygen and primary effluent exist so that the bacteria can be revived and can take up the maximum amount of phosphorus within their cell structure.

5.31 Phosphorus Stripping Tank

1. Control to maintain anaerobic conditions. The most important part of the phosphorus removal system using luxury uptake is the control of the anaerobic tank which causes the bacteria to release phosphorus from their cell structure. This tank must be kept in strict anaerobic conditions and the rate of sludge application into the facility must be at the prescribed design flow. The proper detention time must be maintained within the anaerobic tank in order that the bacteria have enough time to release the phosphorus from the cell structure.
2. Sludge Recycle. The sludge will separate from the liquid within the anaerobic phosphorus stripping tank. The sludge recycle is extremely important. Once the bacteria have released the phosphorus from their cell structure, the activated sludge which is now basically anaerobic, must quickly be returned to the aeration facility in order to revive the bacteria. A great deal of care must be taken to ensure that the sludge return is not too fast nor too slow. Operators should be very careful of this system to ensure proper compatibility with the activated sludge portion of the plant and to maintain the highest efficiency of phosphorus removal using the luxury uptake principle.
3. Effluent from the Phosphate Stripper. The liquid from the anaerobic phosphate stripping tank flows into a chemical clarification unit where lime is used to coagulate and settle the phosphorus which has been released from the bodies of the bacteria. The lime used will be substantially less than the previously-described lime clarification system for phosphorus removal. The luxury uptake and phosphorus stripping process require that lime will be applied to only approximately 10 percent of the entire flow stream. Once the phosphorus has been stripped from the effluent, it is allowed to blend with the secondary effluent prior to tertiary treatment or final disposal.

5.32 Lime Clarification Process

1. Lime Feeding System. The lime feed system for the phosphorus stripping system used in luxury uptake is identical to the system described in the lime clarification section of this chapter. Please refer to Section 5.21 of this chapter for the lime feeding system to understand the basic guidelines used and operational duties.
2. Lime Mixing Tank. The lime slaker and lime mixing tank are identical to the mixing system and feed system described in Section 5.21 of this chapter.
3. Lime Clarification. Lime clarification will be identical to the lime clarification for removal of phosphorus as described in Section 5.21. The only difference will be the smaller flow that will be required using the luxury uptake principle.

5.33 Start-Up, Operation, and Shutdown of Luxury Uptake Phosphorus Stripping Process

5.330 Pre-Start-Up

1. Check lime feed system. The lime feed system should be checked out in very much the same way as that described in Section 5.22 of this chapter.
2. Check sludge recycle and return system. The sludge pumping and piping system functions identically to the system described in Section 5.22. All of the points described in that section should be applied to the operation of the luxury uptake phosphorus removal system described in this section.

5.331 Placing Phostrip Equipment into Operation

1. pH Control. pH control for the lime clarification unit is important and the operator should ensure that pH is above 11.0.

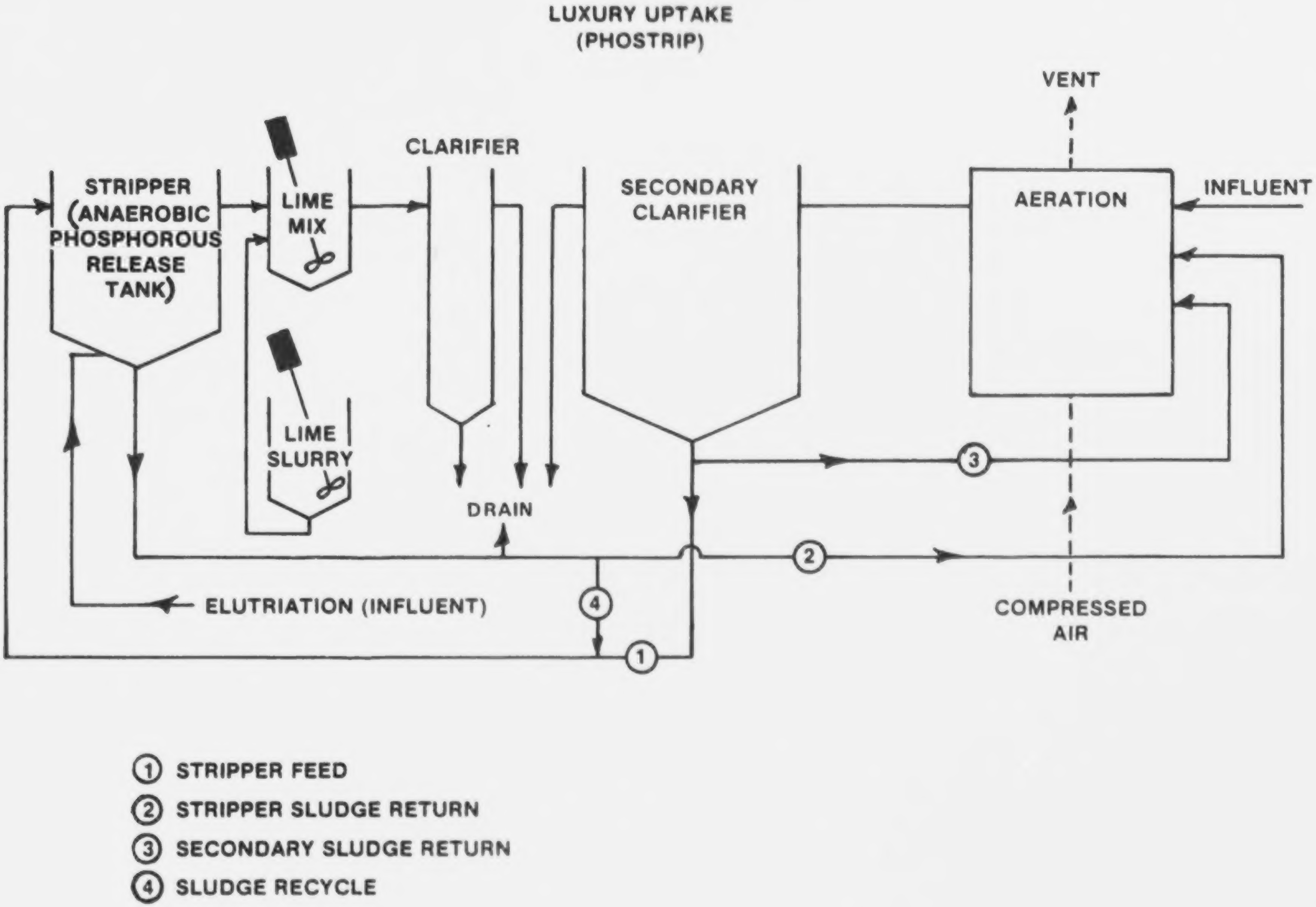

LUXURY UPTAKE
(PHOSTRIP)
VENT
CLARIFIER
STRIPPER (ANAEROBIC PHOSPHOROUS RELEASE TANK)
LIME MIX
SECONDARY CLARIFIER
AERATION
INFLUENT
LIME SLURRY
DRAIN
ELUTRIATION (INFLUENT)
COMPRESSED AIR
①
②
③
④
① STRIPPER FEED
② STRIPPER SLUDGE RETURN
③ SECONDARY SLUDGE RETURN
④ SLUDGE RECYCLE

Fig. 5.4 Luxury uptake of phosphorus (elevation flow diagram)

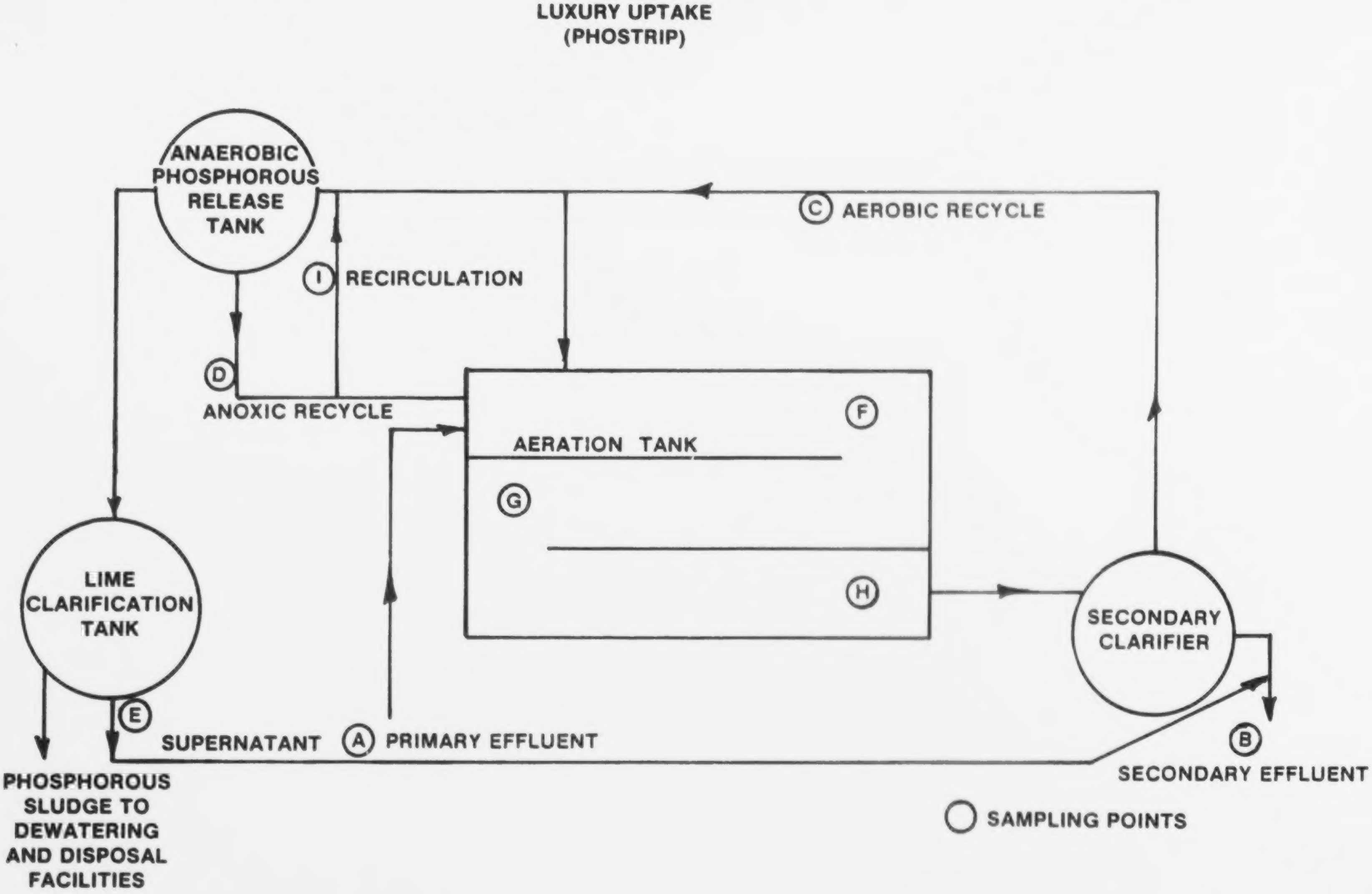

LUXURY UPTAKE
(PHOSTRIP)
ANAEROBIC PHOSPHOROUS RELEASE TANK
Ⓒ AEROBIC RECYCLE
Ⓘ RECIRCULATION
Ⓓ
ANOXIC RECYCLE
Ⓕ
AERATION TANK
Ⓖ
Ⓗ
LIME CLARIFICATION TANK
SECONDARY CLARIFIER
Ⓔ
SUPERNATANT
Ⓐ PRIMARY EFFLUENT
Ⓑ
SECONDARY EFFLUENT
○ SAMPLING POINTS
PHOSPHOROUS SLUDGE TO DEWATERING AND DISPOSAL FACILITIES

Fig. 5.5 Luxury uptake of phosphorus (plan flow diagram)

2. Sludge feed. Sludge feeding into or out of the phosphorus stripping tank must be at proper rates in order to maintain peak efficiencies of phosphorus removal. Refer to the design feed rate in the operation and maintenance manual provided by the design engineer. This feed rate should be complied with as closely as possible in order to prevent excess phosphorus from leaving the stripping tank or to prevent the activated sludge from dying during the anaerobic conditions.
3. Phosphorus separation process. When an anaerobic condition is achieved within the phosphorus stripping tank, the bacteria will release phosphorus as soon as their extinction is threatened. The phosphorus must be removed immediately and it is done so in the liquid stream of the stripping tank. This liquid stream proceeds to the lime clarification tank. The sludge at the bottom of the phosphorus stripping tank is removed and pumped directly to the head of the aeration tank for further luxury uptake of phosphorus and a revival of the bacteria.

5.332 Daily Operation

1. pH Control. Because the liquid stream from the phosphorus stripping tank will be sent to lime treatment for final clarification of the phosphorus, control of the pH above 11 is extremely important. Control of pH, whether it be automatic or manual, must be done properly. Please refer to Section 5.22 on lime clarification in this chapter for details.
2. Phosphorus Stripping Controls. In order to determine the efficiency of the phosphorus stripping tank, the operator should check the laboratory results to determine if more or less time is needed within the stripping tank for the efficient removal of as much phosphorus as possible. Be sure that the activated sludge contained in the phosphorus stripping tank is not totally dead and will be revived within the aeration tank when pumped back to the head of that unit.

5.333 Shutdown of Phosphorus Stripping Process

If the phosphorus stripping process must be shutdown, the treatment facility will operate as a standard activated sludge plant. Instead of a portion of the activated sludge going to an anaerobic phosphorus stripping tank, all of the return sludge will return directly to the aeration tank.

5.334 Return of Activated Sludge Process to Normal Operation

To return the activated sludge part of the treatment facility to normal operation is a quick and easy job. However, there may be certain operational problems that could occur, such as straggler floc and some decrease of the dissolved oxygen uptake rate. These must be checked very closely and the operator should refer to Chapters 8 and 11 of Volumes I and II and Chapter 2 in this manual on activated sludge in order to ensure that the treatment facility is operating in a proper mode.

5.335 Sampling and Analysis

1. pH Control. If the lime clarification process for the phosphorus removal is automatically controlled, a pH test should be manually run on the lime clarification tank each 8 hours to ensure that the automatic controls are functioning properly.
2. Anaerobic Phosphorus Stripping Conditions. A dissolved oxygen probe should be lowered into the anaerobic phosphorus stripping tank to ensure that no dissolved oxygen exists within the tank. If dissolved oxygen exists, it may be a sign that sludge is being fed too fast or withdrawn too fast from the stripping unit.
3. Sludge Return and Reaeration. Returning the sludge at the proper time is very important. Be sure to check at the site where the sludge is returned to the aeration tank to ensure that adequate dissolved oxygen exists within the aeration system. If dissolved oxygen drops substantially, it may be necessary to increase the air supply to that section of the aeration tank where the activated sludge is returned from the anaerobic phosphorus stripping unit.

5.336 Operational Strategy

1. Sludge Flow Quantities. The operator should make certain that sludge flow in and out of the phosphorus stripping tank is at exactly the correct setting. Make sure that flow does not enter too fast; otherwise, anaerobic conditions may be upset and the phosphorus stripping process will be incomplete. Make sure that sludge is withdrawn at a fast enough rate to ensure that the activated sludge does not die and is returned to the aeration tank within the proper time limit.
2. Lime Feed and Clarification. The lime feed and clarification unit must be operated properly. For details on operation, please see Section 5.22 on lime clarification for phosphorus removal.
3. Control of Sludge Withdrawal and Effluent from Lime Clarification Unit. Proper controls must be placed on the pumping of the phosphorus sludge from the clarification unit. These controls are discussed in detail in Section 5.22 on lime clarification for phosphorus removal.
4. Abnormal Operating Conditions. An abnormal condition which may prevail and inhibit the operator's ability to provide sufficient control for phosphorus removal is dissolved oxygen in the phosphorus stripping tank. This phosphorus stripping tank must be maintained at anaerobic or no-oxygen conditions at all times for the release of the phosphorus from the cell structure of the bacteria. Other abnormal conditions can occur in the lime clarification process. Check the abnormal conditions that are found in Section 5.22 on lime clarification for phosphorus removal.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 363.

5.3A What is luxury uptake of phosphorus?

5.3B Where and under what conditions do bacteria release phosphorus from their cell structure in the luxury uptake process?

5.3C List the units (pieces of equipment) used in the lime clarification process of the luxury uptake process.

5.3D How often should the pH be run manually on the lime clarification tank to ensure that the automatic controls are functioning properly?

5.34 Maintenance

5.340 Piping

The piping of a phosphorus stripping process using luxury uptake will be similar to an activated sludge plant except that two additional tanks are provided. Those tanks are the anaerobic stripping tank and the chemical clarification unit. The piping that will need the most care and attention is the lime clarification process piping. Be certain to check the maintenance section on lime clarification for phosphorus removal in Section 5.23 of this chapter.

5.341 Pumps and Equipment

The pumps that pump the activated sludge into and out of the anaerobic phosphorus stripping tank must be operated properly. They must be equipped with variable-speed controls in order that the operator can adjust the feed rate into and out of the anaerobic phosphorus stripping unit. The pumps and equipment must be maintained so that the activated sludge is properly pumped into and out of the phosphorus stripping unit. The bacteria found in the activated sludge must not release phosphorus until they have reached the anaerobic stripping tank. Also, the activated sludge that has undergone anaerobic conditions must be returned to the aeration system as quickly as possible.

5.342 Lime Feed

The lime feed equipment is similar to that described in the previous section. Be sure to check the maintenance portion of Section 5.23 on lime feed for phosphorus removal because it is applicable for luxury uptake processes using lime clarification.

5.343 Lime Slurry and Mixing Operation

The lime slurry and mixing operation must be kept clean at all times. Be sure to read Section 5.23 on maintenance in the previous portion of this chapter describing lime clarification for phosphorus removal.

5.344 Sludge Withdrawal and Disposal Pumps

The lime sludge pumps must be kept clean at all times because of the ability of lime to stick to all surfaces. The operator should read Section 5.23 on how to maintain pumps and other equipment when using a lime precipitation method for phosphorus removal.

5.35 Safety

1. Lime. Lime is a very strong base and can cause serious burns and other injuries to portions of the human body. Be sure to read the precautions described in Section 5.24 of this chapter.
2. Gases Off the Anaerobic Phosphate Stripping Tank. As with any unit of wastewater treatment, whenever anaerobic conditions prevail, certain gases are released from the tank. Just as it is important not to smoke around an anaerobic digester, it is also important not to smoke around an anaerobic phosphorus stripping tank. The gases given off could include methane which could cause explosions or a fire. Operators must understand and be very cautious around any tank where anaerobic conditions exist and from which explosive gases may be emitted.

5.36 Loading Guidelines

1. Typical Loading Rates. Because the use of luxury uptake and phosphorus stripping in anaerobic conditions is relatively new, loading rates for various units will depend on the design and the operation of that specific treatment facility.
2. Hydraulic Loading for Phosphate Stripper. The hydraulic loading for a phosphate stripper depends on the dissolved oxygen of the activated sludge when it enters the anaerobic stripper and it also depends on the ability of the anaerobic phosphate stripper to remain anaerobic at all times during the expulsion of phosphorus from the cell structure of the bacteria.
3. Hydraulic Loading Rate for Lime Clarifier. The hydraulic loading rate for lime clarification units is described in Section 5.25 on lime clarification for phosphorus removal. Please check Section 5.25 for average loading rates for the chemical clarification units.

5.37 Review of Plans and Specifications

1. Lime Storage and Unloading Facilities at the Treatment Plant. If time is used to coagulate and settle phosphorus from the waste stream of the phosphorus stripping tank, it is very useful if the operator can provide information to the design engineer and have the opportunity to review the plans and make comments. Some of the items to look for in the design of the lime storage area are included in Section 5.26 on lime clarification for phosphorus removal.
2. Maintaining Proper Dissolved Oxygen. The operator may want to insist on automatic dissolved oxygen probes which can help to determine if the proper anaerobic conditions exist in the phosphorus stripping unit to ensure that phosphorus is released from the cell structure of the bacteria. Warning signals and devices can be included to ensure that the operator is notified if oxygen is recorded in the stripping tank. Automatic dissolved oxygen meters and controls can be very useful in maintaining adequate dissolved oxygen within the aeration system after the anaerobically treated sludge has been returned to the aeration tanks.

5.38 Additional Reading on Phosphorus Removal by Luxury Uptake Using an Anaerobic Phosphorus Stripping Tank

1. *BIOLOGICAL-CHEMICAL PROCESS FOR REMOVING PHOSPHORUS* by Union Carbide Corporation under a grant by the U.S. Environmental Protection Agency, Cincinnati, Ohio.
2. *THE PHOSTRIP PROCESS* by Union Carbide Corporation, Tanawanda, New York.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 363.

5.3E How can lime be harmful to your body?

5.3F Why should you not smoke around a phosphorus stripping tank?

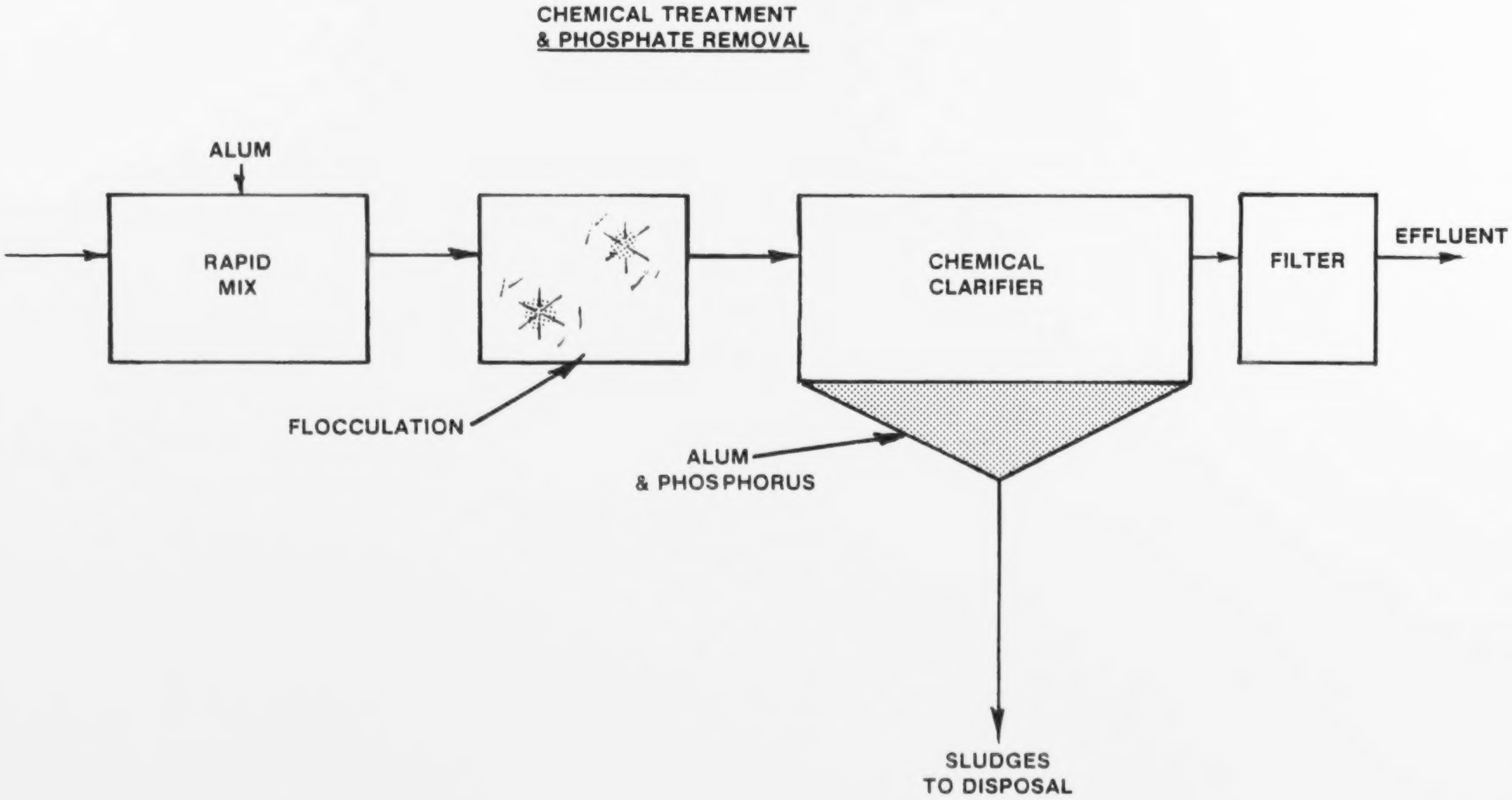
5.3G Why might an operator insist on automatic dissolved oxygen probes in the phosphorus stripping unit?

5.4 PHOSPHORUS REMOVAL BY ALUM FLOCCULATION

5.40 Variations in the Alum Flocculation Process

5.400 Alum Flocculation as Used in a Clarification Process (Fig. 5.6)

Aluminum sulfate (alum) can be used in the same manner as lime for precipitation of phosphorus in a clarifier. The same principles of coagulation, flocculation and sedimentation apply when using alum for the removal of phosphorus in effluent from a secondary treatment facility. However, because of the difference in cost between aluminum sulfate and lime, lime is more commonly used for the precipitation of phosphorus.


CHEMICAL TREATMENT
& PHOSPHATE REMOVAL
ALUM
RAPID MIX
FLOCCULATION
CHEMICAL CLARIFIER
ALUM & PHOSPHORUS
FILTER
EFFLUENT
SLUDGES TO DISPOSAL

401

402

Fig. 5.6 Alum flocculation as used in a clarification process

When alum is used for phosphorus removal, two general reactions occur. In the first reaction, alum reacts with the alkalinity of the wastewater to form an aluminum hydroxide floc.

$$\begin{array}{ccccccccc} \text{Alum} & + & \text{Alkalinity} & \rightarrow & \text{Aluminum Hydroxide Floc} & + & \text{Sulfate} & + & \text{Carbon Dioxide} \\ Al_2(SO_4)_3 & + & 6\,HCO_3^- & \rightarrow & 2\,Al(OH)_3\downarrow & + & 3\,SO_4^{-2} & + & CO_2 \end{array}$$

The alum also reacts with the phosphate present.

$$\begin{array}{ccccccc} \text{Alum} & + & \text{Phosphate} & \rightarrow & \text{Aluminum Phosphate} & + & \text{Sulfate} \\ Al_2(SO_4)_3 & + & 2\,PO_4^{-3} & \rightarrow & 2\,Al\,PO_4\downarrow & + & 3\,SO_4^{-2} \end{array}$$

Phosphorus removal is by the formation of an insoluble complex precipitate and by adsorption on the aluminum hydroxide floc. Depending on the alkalinity of the wastewater, dosages of 200 to 400 mg/*L* of alum are commonly required to reduce phosphorus in the effluent down to 0 to 0.5 mg/*L*. Optimum phosphorus removal is usually achieved around a pH of 6.0. Alum feed is frequently controlled by automatic pH equipment which doses according to the pH set point (the more alum, the lower the pH). Jar tests can be used to determine the optimum pH set point and alum dosage rate.

If it is necessary to achieve low effluent phosphorus residuals (less than 1.0 mg/*L*) in the effluent, the chemical clarifier is usually followed by either a pressure filter or a multi-media gravity filter. Phosphorus sludge from the clarifier goes to dewatering and disposal facilities. At present, there are no economical methods available for alum recovery.

5.401 Alum Flocculation as Used in Conjunction with Filtering of Suspended Solids (Fig. 5.7)

1. Aluminum Sulfate (Alum) as a Coagulant. Because of the proven ability of alum to coagulate and flocculate suspended particles from water and wastewater, the use of alum as a filtering aid has been common for many years. When alum is added to the wastewater entering a filtration unit, electromagnetic forces are established on the filter media which allow the trapping of suspended solids and substantially improve the quality of effluent.

   Treatment plants which have used aluminum sulfate as a filtering aid have also experienced a reduction in the phosphorus as the wastewater flows through the filtration units. Although filtration is not usually considered an efficient method to remove phosphorus, the filtering with alum addition has provided a reduction of phosphorus at the same time that BOD and suspended solids are being reduced from the wastewater.

2. Expected Efficiencies of Phosphorus Removal Using Alum in Conjunction with Filtration. Most advanced wastewater treatment facilities which use a phosphorus removal system followed by filtration can expect that low levels of phosphorus would enter the filter unit. Experiences at various wastewater treatment facilities have indicated that total phosphorus removal through filters using alum as a filtering aid achieved 70 to 95 percent phosphorus removal efficiencies. Influent data indicated a total phosphorus, however, of less than one milligram per liter. Dissolved phosphorus can be reduced 65 to 90 percent assuming that the incoming phosphorus loading would be less than 0.5 mg/*L*. Particulate phosphorus can be removed up to 100 percent because this phosphorus is usually attached to suspended solids which are almost totally removed from the wastewater as it passes through a properly operated filter using aluminum sulfate for coagulation.

5.41 Maintenance of Alum Feeding Pumps and Associated Equipment

1. Pump Plugging Problems. Aluminum sulfate usually is delivered in a dry powder form or as a liquid; however, it is used as a liquid. The operators of a treatment facility must mix the dry alum with water to obtain a solution for feed to the water before entrance to the filtration units. Because of the chemical nature of aluminum sulfate, it sticks to surfaces very easily. This has caused pump plugging problems for many treatment plants. Most of the pumps that feed aluminum sulfate are small, metered, chemical feed pumps. Alum has a tendency to plug these pumps very rapidly and therefore, the pumps require a considerable amount of care and maintenance to ensure that the proper dosage of alum is being fed to the filtration units. If plugging problems occur, the accuracy of the feed amount is questionable.

2. Pipe Plugging and Deterioration. Most pipes used for the transport of aluminum sulfate are either plastic or small glass tubing. Alum can stick to most surfaces and can deteriorate metal due to the chemical reaction formed when the aluminum sulfate and ferrous metal react with one another. Once liquid aluminum sulfate dries, plugging is a certain result. Pipes may become permanently plugged with aluminum sulfate and require replacement. The operators should keep pumps and pipes clean and should remember to run clear water periodically through an alum feedline to be sure that any potential plugging problems are alleviated.

5.42 Operation of Alum Flocculation for Phosphorus and Suspended Solids Removal

5.420 Daily Operating Procedures

When used as a filtration aid, aluminum sulfate dosages must be precise. Even slight over or under doses may cause reduced efficiency. The operator must rely on jar testing and sampling of influent and effluent from a filter bed to be certain that the feed rate or dosage of alum in milligrams per liter is correct for the optimum phosphorus and suspended solids removal efficiency. The operator should perform the following steps to be certain that aluminum sulfate feed is at the correct ratio:

1. Check the results of jar tests to be certain the dosage of alum will form a good floc.
2. Check laboratory results to be certain that the alum is not overdosed or underdosed so that phosphorus also is removed as efficiently as possible through the filtration unit.
3. Check chemical feed pumps and alum feed piping system to be certain that the setting on the pump actually corresponds to the desired feed rate for efficient operation.

5.421 Abnormal Conditions

1. Pump or Piping Plugging Problems. As mentioned previously, the most important maintenance item for any alum feeding system is keeping the aluminum sulfate from plugging either piping or the chemical feed pump used for the feed of the alum (aluminum sulfate).
2. Operational Problems with Upstream or Downstream Treatment Processes. Tertiary filtration depends to a great extent on the upstream treatment units functioning properly. The operator should be certain of the quality of the wastewater entering the filtration unit. This quality can change daily depending on the upstream processes and the efficiency of their performance. The operator must

FILTRATION

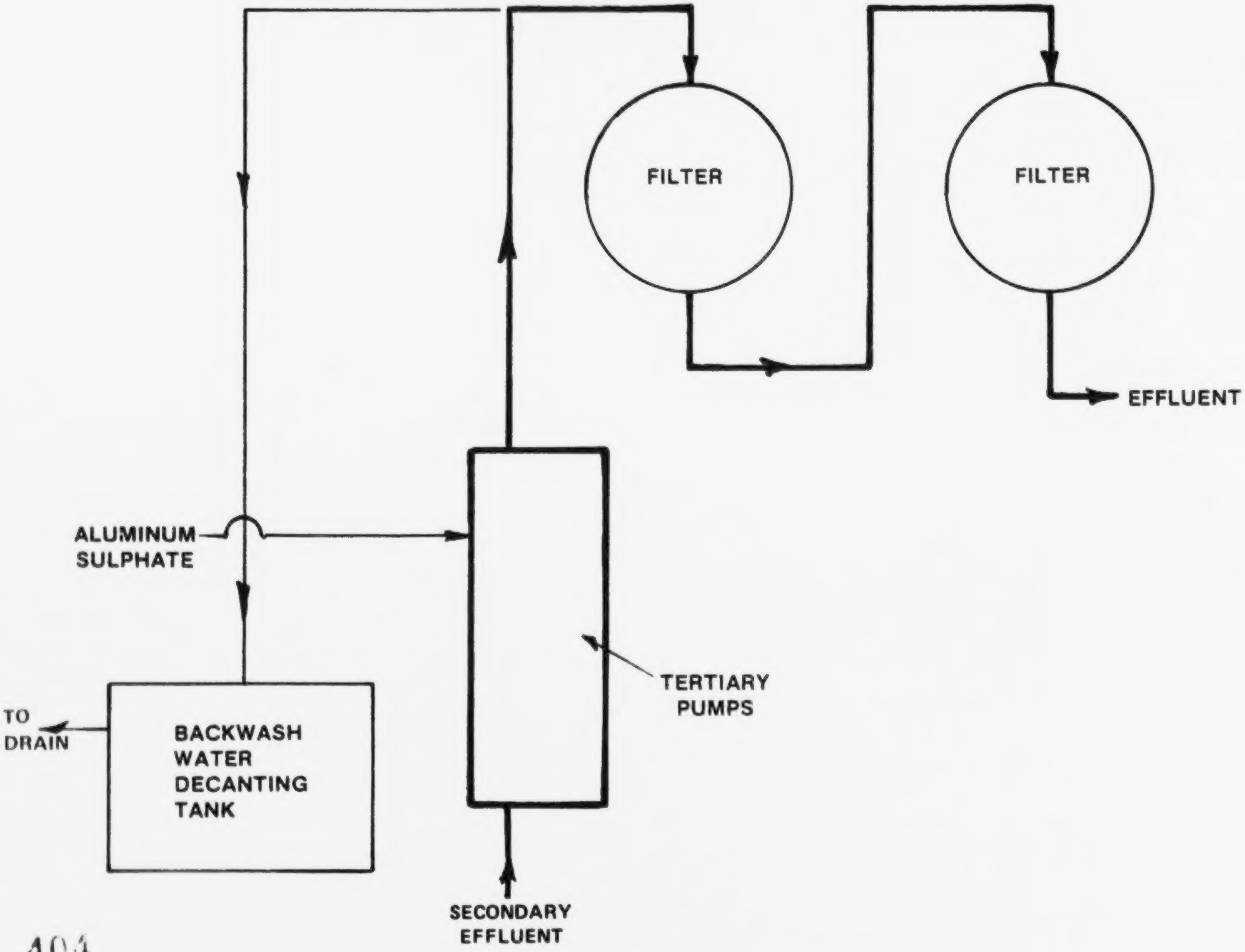

FILTER
FILTER
EFFLUENT
ALUMINUM SULPHATE
TERTIARY PUMPS
TO DRAIN
BACKWASH WATER DECANTING TANK
SECONDARY EFFLUENT

Fig. 5.7 Alum flocculation as used in conjunction with filtering of suspended solids

check the various guidelines including suspended solids loading to calculate and to adjust the dosage of chemicals needed in the filtration unit. Filters also require backwashing to keep them clean and in proper operation. If upstream treatment units are not functioning properly, backwashing cycles may be needed more frequently than normal.

3. Alum Overdoses. One of the most common problems with using chemicals as filtering aids is the possibility of overdosing the filters with the chemical. Aluminum sulfate will react in a very negative way when it is overdosed into a wastewater system. The result is a lowering of the pH; this will hinder the ability of alum to coagulate the suspended solids. The low pH causes a cloudy condition which is visible to the operator in the form of substantial turbidity and suspended solids. If you observe a cloudy appearance in the effluent from the filtration unit, first check to make sure that the alum feed is not in an overdose condition. Underfeeding alum sulfate is better than overdosing with the chemical.
4. Suspended Solids Interference. If treatment units upstream are not operating properly, a substantial amount of suspended solids will load up the filter units and interfere with their ability to remove both suspended solids and phosphorus. From the standpoint of efficient operation, overloading of suspended solids onto the filtration units must not occur. If this occurs, frequent backwashing will be required and an increased quantity of aluminum sulfate and/or polymer may have to be added to overcome the additional load placed on the filter units.

5.43 Safety

1. Aluminum Sulfate Mixed with Water. When aluminum sulfate mixes with water, a very slippery combination occurs. Operators should be very cautious around any floor that is wet with a spill of aluminum sulfate. Any surface continually exposed to slippery aluminum sulfate should be roughed up to prevent slipping and to avoid injury. Safety railings should be provided near any containers or working areas in which aluminum sulfate can be found.
2. Materials Handling Precautions. Aluminum sulfate usually is delivered in a dry powder form. The operator should be very careful when mixing the powder with water that the powder does not get into the operator's respiratory system or eyes. Protective goggles and masks should be worn to protect your eyes and respiratory system. Use fans and filters to provide a safe air for breathing in the work area. The operator should also be careful not to allow powdered aluminum sulfate to fall on a wet surface, thereby creating a slippery condition.

5.44 Loading Guidelines

1. Alum Feed Rates for Effective Suspended Solids Removal. Aluminum sulfate is usually added as a filtering aid to remove suspended solids. The dosage rates at various treatment facilities range from 1 to 20 milligrams per liter depending on the incoming suspended solids and wastewater quality. Some phosphorus also will be removed with the suspended solids, but this procedure and dosage do not produce substantial phosphorus removal. See Section 5.400 for information on how to remove phosphorus by the use of alum. To determine the best operating dosage for aluminum sulfate at your facility, you should rely on jar tests and other laboratory results to determine the best dosage rate for your treatment facility and type of wastewater. The feed rates of aluminum sulfate are usually low; therefore, be certain that the chemical feed pump is operating properly to provide an accurate chemical-flow ratio.
2. Hydraulic Loading on Filtration Process Using Aluminum Sulfate as a Filtering Aid. The standard design rate for a pressure filtration unit is 5 gallons per minute per square foot (3.4 liters per second per square meter). Loading rates can vary depending on the type of filter system used. The most commonly used is the pressure filter. The operator should calculate the hydraulic loading based on the flow of wastewater distributed over the surface area of the filtration unit. If a gravity filter unit is used, the operator should obtain information from the manufacturer or design engineer on the proper application rate of wastewater onto the unit.

5.45 Review of Plans and Specifications

1. Storage of Aluminum Sulfate. Because aluminum sulfate comes in a powdered form, it is important to store the product in a dry environment, preferably inside a building. Usually operators make up a large batch of aluminum sulfate liquid at one time in order to have enough on hand to last several days. The tanks holding the liquid aluminum sulfate should be fiberglass, non-ferreous material or be rubber-lined to protect the metal from the corrosive effects of the aluminum sulfate.
2. Piping and Pump Diagrams. Because aluminum sulfate has the capability of sticking to many surfaces, it is important for the design of a treatment facility using alum to have flexible piping so that if a feedline becomes plugged or a pump is out of service for maintenance, the alum feed can continue without interruption. A pipe chase will enable operators to get to the alum piping in order to make repairs or replace the pipe if needed. A system of flushing the pumps and piping is necessary to help prevent any plugging problems which can plague the operation of a facility.

5.46 Additional Reading for Phosphorus Removal by Alum Flocculation

1. *HANDBOOK OF ADVANCED WASTEWATER TREATMENT,* Second Edition, Culp, Russell L., George M. Wesner, and Gordon L. Culp, Van Nostrand Reinhold Co., New York City, New York, 1977. Obtain from Litton Educational Publishing, Inc., 7625 Empire Drive, Florence, Kentucky 41042. Price: $35.00.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 363.

5.4A What is a major difference between the use of lime and alum for precipitation of phosphorus-rich particles?

5.4B How would you determine the optimum alum dosage?

5.4C If upstream treatment units are not functioning properly, what happens to filter backwashing cycles?

5.4D What would you do if you observed a cloudy appearance in the effluent from a filtration unit?

5.4E What should be done to a floor that is continually exposed to slippery alum?

END OF LESSON 2 OF 2 LESSONS
ON
PHOSPHORUS REMOVAL

Please answer the discussion and review questions before continuing.

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. PHOSPHORUS REMOVAL

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

6. What happens to the effluent from the phosphate stripper?
7. In the luxury uptake process, what happens if the sludge feed rate is (a) too high or (b) too low into or out of the phosphorus stripping tank?
8. How would you adjust the feed into and out of an anaerobic phosphorus stripping tank?
9. Alum has proved to be an effective coagulant for removing what pollutants from wastewater?
10. Why do pumps moving alum solutions clog?
11. How would you keep alum feed lines from plugging?

PLEASE WORK THE OBJECTIVE TEST NEXT.

SUGGESTED ANSWERS

Chapter 5. PHOSPHORUS REMOVAL

Answers to questions on page 342.

5.0A Phosphorus is removed from wastewater because it provides a nutrient or food source for algae. Dead algae can cause serious oxygen depletion problems in receiving streams which in turn can kill fish and other aquatic life. Also, algae can cause taste and odor problems in drinking water supplies.

5.1A The three major types of systems used to remove phosphorus from wastewater are:

1. Lime precipitation;
2. Luxury uptake; and
3. Aluminum sulfate flocculation and precipitation.

Answers to questions on page 350.

5.2A Equipment necessary for the lime precipitation process include:

1. Lime feed equipment;
2. Mixing equipment and mixing chamber;
3. Clarifiers; and
4. Pumps and piping.

5.2B The slaker or lime mix feed system must have a grit removal system because most dry lime has a certain amount of grit, rocks and sand in the mixture. This material must be removed to prevent plugging and equipment wear.

5.2C Daily operation of a lime precipitation process to remove phosphorus consists of:

1. Routine pH monitoring to check automatic feed;
2. Routine phosphate test for removal efficiencies;
3. Calcium oxide content of lime feed; and
4. Daily maintenance of pumps, piping, and other equipment to prevent plugging by lime scale.

5.2D Low flow conditions are of concern to avoid the possibility of feeding excess lime and thereby wasting lime and money.

5.2E Phosphorus removal efficiency may be affected by:

1. Short-circuiting;
2. Changes in pH;
3. Solids loading;
4. Small straggler floc;
5. Storm water;
6. Industrial dischargers;
7. Plugged pumps or piping;
8. Inadequate lime supply; and
9. Operational problems with upstream or downstream treatment processes.

Answers to questions on page 352.

5.2F The purpose of the lime slaking mechanism is to convert calcium oxide to calcium hydroxide in a slurry form.

5.2G Recalcined lime is lime from a lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).

5.2H Many times a lime process uses polymers to help form colloidal particles of lime and phosphorus to provide faster sedimentation in a lime clarification unit.

5.2I The forms of phosphorus in the total phosphate measurement include the forms of orthophosphate, polyphosphate and organic phosphorus.

5.2J To reduce problems that will arise when pumps or pipes become plugged with lime, alternate piping and valving should be provided so that while repairing or cleaning one pipe train or pump, continued operation can be provided.

END OF ANSWERS
TO
QUESTIONS IN LESSON 1

Answers to questions on page 356.

5.3A Luxury uptake of phosphorus is a biological process whereby the bacteria normally found in the activated sludge treatment portion of the secondary wastewater treatment plant are withdrawn to an environment without oxygen (anaerobic) for release of phosphorus. When these bacteria are returned to an ideal environment, the first thing they take in is phosphorus. This phosphorus take-up is known as luxury uptake.

5.3B In the luxury uptake process, bacteria release phosphorus from their cell structure in the phosphorus release tank under anaerobic conditions.

5.3C The units used in the lime clarification process of the luxury uptake process include:

1. Lime slaking equipment,
2. Lime feeding system, and
3. Lime clarification unit.

5.3D The pH should be run manually on the lime clarification tank each 8 hours to ensure that the automatic controls are functioning properly.

Answers to questions on page 357.

5.3E Lime is a very strong base and can cause serious burns and other injuries to your body.

5.3F You should not smoke around a phosphorus stripping tank because the methane gas produced by the anaerobic conditions can create explosive conditions just like in an anaerobic digester.

5.3G An operator may insist on automatic dissolved oxygen probes to determine that continuous anaerobic conditions exist in the phosphorus stripping unit to ensure that phosphorus is released from the cell structure of the bacteria.

Answers to questions on page 361.

5.4A A major difference between lime and alum for precipitation of phosphorus rich-particles is that alum is more expensive than lime.

5.4B The optimum alum dosage can be determined by the jar test. Add varying amounts of alum to each jar containing the water being treated. The jar that produces the best clarification with the minimum amount of alum indicates the optimum alum dosage.

5.4C If upstream treatment units are not functioning properly, filter backwashing cycles may be more frequent than normal.

5.4D If you observe a cloudy appearance in the effluent from a filtration unit, first check to make sure that the alum feed is not in an overdose condition.

5.4E Any floor that is continually exposed to slippery alum should be roughed up to prevent slipping and to avoid injury.

**END OF ANSWERS
TO
QUESTIONS IN LESSON 2**

OBJECTIVE TEST

Chapter 5. PHOSPHORUS REMOVAL

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. Recalcine is a lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).
   1. True
   2. False
2. In the lime phosphorus removal process, the lime phosphorus sludge is pumped from the chemical clarifier to an anaerobic digester.
   1. True
   2. False
3. Calcium carbonate and carbon dioxide combine to form calcium hydroxide.
   1. True
   2. False
4. Pumps handling lime sludges are not subject to wear because the lime forms a protective coating over the moving parts.
   1. True
   2. False
5. The use of alum and filtration can remove *BOTH* dissolved and particulate phosphorus from wastewater.
   1. True
   2. False
6. Chemicals used to remove phosphorus from wastewater include
   1. Aluminum sulfate.
   2. Calcium hydroxide.
   3. Chlorine.
   4. Copper sulfate.
   5. Lime.
7. Lime feeding equipment should be routinely checked
   1. Every hour.
   2. Several times during each shift.
   3. Once each shift.
   4. Three times a week.
   5. Once a week.
8. The plugging of pipes by limestone scale in a lime system can be prevented by
   1. Backwashing.
   2. Forward flushing.
   3. Regular cleaning with hot water or steam.
   4. Regular recarbonation.
   5. Washing with hydrochloric acid.
9. In a properly operated chemical clarifier you can see down below the water surface at least
   1. 1 foot.
   2. 2 feet.
   3. 4 feet.
   4. 7 feet.
   5. 10 feet.
10. In the lime precipitation process for phosphorus removal, the pH of the combined wastewater and lime slurry should be ______ or above.
    1. 5
    2. 7
    3. 8
    4. 9
    5. 11
11. The pH probe or sensing mechanism that helps the lime feed system work in automatic mode must be cleaned on ______ basis to ensure that a scale buildup does not interfere with the function of the pH control readout probe.
    1. An hourly
    2. A two-hour
    3. A daily
    4. An every other day
    5. A weekly
12. In the luxury uptake process, the pH in the lime clarification unit should be above (choose the most accurate answer)
    1. 3.0.
    2. 5.0.
    3. 7.0.
    4. 9.0.
    5. 11.0.
13. The hydraulic loading for a phosphate stripper depends on the
    1. Ability of the anaerobic phosphate stripper to remain anaerobic.
    2. Ability of the aerobic phosphate stripper to remain aerobic.
    3. BOD loading of the unit.
    4. Dissolved oxygen of the activated sludge.
    5. pH of the wastewater being treated.
14. Most pipes used for the transport of aluminum sulfate are made of which of the following materials?
    1. Asbestos cement
    2. Cast iron
    3. Copper
    4. Glass
    5. Plastic

END OF OBJECTIVE TEST

CHAPTER 6

NITROGEN REMOVAL

by

John G. M. Gonzales

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Chapter 6. Nitrogen Removal

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OBJECTIVES

Chapter 6 NITROGEN REMOVAL

Following completion of Chapter 6, you should be able to do the following:

1. Explain why nitrogen is removed from wastewater,
2. Identify the types of nitrogen removal systems,
3. Describe nitrification and denitrification processes,
4. Operate nitrification and denitrification processes,
5. Describe the differences between suspended growth and fixed film reactors,
6. Explain how ammonia stripping, breakpoint chlorination and ion exchange processes remove nitrogen, and
7. Describe the two basic types of hyacinth culture systems and how they remove nutrients from secondary effluent.

GLOSSARY

Chapter 6 NITROGEN REMOVAL

ATTACHED GROWTH PROCESSES ATTACHED GROWTH PROCESSES

Wastewater treatment processes in which the microorganisms and bacteria treating the wastes are attached to the media in the reactor. The wastes being treated flow over the media. Trickling filters and rotating biological contactors are attached growth reactors. These reactors can be used for BOD removal, nitrification and denitrification.

DENITRIFICATION (dee-NYE-tri-fi-KAY-shun) DENITRIFICATION

(1) The anaerobic biological reduction of nitrate nitrogen to nitrogen gas. (2) The removal of total nitrogen from a system. (3) A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological floc in the activated sludge process and float the floc to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers or gravity thickeners. See *NITRIFICATION.*

ENDOGENOUS (en-DODGE-en-us) ENDOGENOUS

A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.

FIXED FILM FIXED FILM

Fixed film denitrification is the common name for attached growth anaerobic treatment processes used to achieve denitrification.

HETEROTROPHIC HETEROTROPHIC

Describes plants or animals, including bacteria and other microorganisms, that use organic matter for energy and growth.

METABOLISM METABOLISM

All of the processes or chemical changes in an organism or a single cell by which food is built up (anabolism) into living protoplasm and by which protoplasm is broken down (catabolism) into simpler compounds with the exchange of energy.

NITRIFICATION (NYE-tri-fi-KAY-shun) NITRIFICATION

A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the "nitrification stage." (First-stage BOD is called the "carbonaceous stage.") See *DENITRIFICATION.*

PROTOPLASM PROTOPLASM

A complex substance (typically colorless and semifluid) regarded as the physical basis of life, having the power of spontaneous motion and reproduction; the living matter of all plant and animal cells and tissues.

SUBSTRATE SUBSTRATE

The base on which an organism lives. The soil is the substrate of most seed plants where rocks, soil, water, or other tissues are substrates for other organisms.

SUSPENDED GROWTH PROCESSES SUSPENDED GROWTH PROCESSES

Wastewater treatment processes in which the microorganisms and bacteria treating the wastes are suspended in the wastewater being treated. The wastes flow around and through the suspended growths. The various modes of the activated sludge process are suspended growth reactors. These reactors can be used for BOD removal, nitrification and denitrification.

ZOOGLEAL MASS (ZOE-glee-al) ZOOGLEAL MASS

A complex population of organisms that form a "slime growth" on the trickling filter or packed tower media. These organisms break down the organic matter and convert ammonia to nitrate in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris. "Slime growth" is a more commonly used term.

CHAPTER 6 NITROGEN REMOVAL

NOTE: For a review of previous discussions, read Chapter 2, "Activated Sludge," Section 2.6, "Effluent Nitrification, pages 101 to 105.

6.0 WHY IS NITROGEN REMOVED FROM WASTEWATER?

6.00 Nitrogen as a Nutrient

Inorganic nitrogen provides a nutrient or food source for algae and a combination of nitrogen and phosphorus in receiving waters can cause algal growths to multiply rapidly. Algae in water are unsightly and cause tastes and odors in a drinking water supply. Dead and decaying algae can result in oxygen depletion problems in receiving waters which in turn adversely affect aquatic life. Fish kills in receiving water can result from an oxygen deficiency and/or ammonia toxicity in receiving waters.

NITROGEN
N
PHOSPHORUS
P
ALGAE

By removing nitrogen from the effluent of the wastewater treatment facility, the lake or river that a treatment plant discharges into will not contain one of the nutrients essential for algal growth. The reduction in the nitrogen nutrient thus reduces the growth of algae. However, in most receiving waters phosphorus is the limiting nutrient; therefore, nitrogen removal will have little impact on algal growth.

6.01 Need for Nitrogen Removal

The United States Environmental Protection Agency and other state water pollution control regulatory agencies recognize the need to protect receiving streams from problems that occur because of the growth of algae. The regulatory agencies are requiring that wastewater treatment plants discharging to sensitive receiving waters remove nitrogen in the effluent to protect a river, stream or lake by eliminating that nutrient from the algal food chain. Nitrogenous compounds must also be controlled in plant effluents to prevent adverse impacts from ammonia toxicity to fish life, reduction of chlorine disinfection efficiency, an increase in the dissolved oxygen depletion in receiving waters, adverse public health effects (mainly in groundwater used for drinking where high nitrate levels can interfere with oxygen utilization in newborn babies), and a reduction in the suitability for reuse.

6.1 TYPES OF NITROGEN REMOVAL SYSTEMS

Nitrification/denitrification, ammonia stripping, and breakpoint chlorination are the most common types of nitrogen removal systems. Ion exchange is also sometimes used. Hyacinth cultures and overland flow systems can remove nitrogen from secondary effluents. Table 6.1 is a summary of types of nitrogen removal systems and operational considerations associated with each process.

TABLE 6.1 TYPES OF NITROGEN REMOVAL SYSTEMS

SYSTEM	OPERATIONAL CONSIDERATIONS
1. PHYSICAL TREATMENT METHODS	1. Expensive
A. Sedimentation B. Gas Stripping	
2. CHEMICAL TREATMENT METHODS	2. Expensive
A. Breakpoint Chlorination B. Ion Exchange	
3. BIOLOGICAL TREATMENT METHODS	
A. Activated Sludge Processes B. Trickling Filter Processes C. Rotating Biological Contractor Processes D. Oxidation Pond Processes	3. A-D Operational control. Additional costs for oxygen to produce nitrification.
E. Land Treatment Processes (Overland Flow) F. Wetland Treatment Systems (Hyacinth Cultures)	3. E & F Land requirements. Suitable temperatures. Control of plants.

6.10 Nitrification

Nitrification is an extremely important treatment process in terms of effluent treatment to reduce the nitrogen oxygen demand (NOD) on receiving waters. The conversion of ammonia to nitrate in a treatment plant requires significant amounts of oxygen which would have to be supplied by receiving waters if an effluent contains ammonia instead of nitrate. For nitrogen to be removed from an effluent, the process must consist of both nitrification *AND* denitrification (nitrification/denitrification).

Nitrification is a biological process accomplished primarily by two types of bacteria: *Nitrosomonas* and *Nitrobacter*. Unlike most of the common organisms found in a wastewater treatment facility, these microorganisms derive energy from inorganic compounds such as ammonium nitrogen. The first step in this process is the conversion of ammonium (NH_4^+) to nitrite (NO_2^-) by *Nitrosomonas* bacteria. The second step is conversion of nitrite to nitrate (NO_3^-) by *Nitrobacter* bacteria. In wastewater treatment the proper conditions must exist for *Nitrosomonas* to be able to separate the nitrogen from the hydrogen in the ammonium molecule and replace the hydrogen with oxygen molecules. Sufficient oxygen and the appropriate temperature and microbiological food must be present to accomplish this process. *Nitrobacter* also rely on oxygen to complete the stabilization of the nitrite molecule into the more stable nitrate substance. Again, adequate amounts of free oxygen and food source as well as optimal temperature and bacteria population along with other conditions are required to complete this reaction.

BIOLOGICAL DENITRIFICATION
BACTERIAL DISSEMINATION
NITRATE DISSIMILATION
NITRATE • NITRITE
NO • N2O • or N2
DENITRIFICATION
SUSPENDED GROWTH REACTIONS

6.11 Denitrification

Biological denitrification is the process by which bacteria reduce nitrate (NO_3^-) to gaseous nitrogen forms, primarily nitrous oxide (N_2O) and nitrogen gas (N_2). A number of bacterial species that naturally occur in wastewater accomplish denitrification. In all cases the bacteria are heterotrophic since they can metabolize complex organic substances. The bacteria are strong enough to use nitrate oxygen during a process called bacterial dissimilation.

Nitrate dissimilation takes place in two steps. First, nitrate is reduced to nitrite. Next, nitrite is reduced by the bacterial dissimilation process to form nitric oxide (NO), nitrous oxide (N_2O) or nitrogen gas (N_2).

Placed in an environment that has no free oxygen but containing a defined carbon food source, denitrifying bacteria will reduce nitrate to nitrogen gas by using the oxygen found in the nitrate molecule. This occurs during the metabolic process of breaking down the carbon food source. Denitrification is accomplished using attached growth reactors (fixed film denitrification), or within a modified activated sludge process (also known as suspended growth denitrification).

6.12 Ammonia Stripping

Ammonia nitrogen in the gaseous ammonia (NH_3) form (and only in the gaseous form) has a natural tendency to leave the wastewater and enter the atmosphere. Therefore, for ammonia stripping to work efficiently, the bulk of the ammonium (NH_4^+) (the natural form of "ammonia" in wastewater) must be first converted to the gaseous ammonia (NH_3) form by adding chemicals to increase the pH level of the wastewater up to the 10.5 to 11.5 range. Then, when this pH level is achieved, a mixture of wastewater droplets and air will result in the ammonia being stripped (removed) from the droplets by the air. This mixing of wastewater and air is accomplished in an ammonia stripping tower where the high pH wastewater falls over fixed media or is sprayed into the air while a blower continuously forces fresh air into the mixture to strip off more ammonia.

6.13 Breakpoint Chlorination

Ammonia nitrogen can be oxidized to nitrogen gas (N_2) through the use of chlorine. Breakpoint chlorination is the term used to describe this process. In the breakpoint chlorination process chlorine is added until the ammonia nitrogen has been oxidized to nitrogen gas. This point is achieved when further additions of chlorine result in an increase in the chlorine residual of the water being treated.

Breakpoint chlorination requires relatively large amounts of chlorine per unit of ammonia removed. The expense and danger of removing high concentrations of ammonia nitrogen by breakpoint chlorination are prohibitive. Consequently, breakpoint chlorination is used primarily to remove small amounts of ammonia nitrogen remaining after wastewater has been treated with other nitrogen removal processes. Polishing treatment plant effluent by decreasing the small amounts of remaining ammonia nitrogen is the recommended use for the breakpoint chlorination process.

The chlorine to ammonia nitrogen ratio is normally around 10:1. In other words, for every one mg/*L* of ammonia nitrogen, ten mg/*L* of chlorine are necessary to oxidize the ammonia to nitrogen gas.

6.14 Ion Exchange

The ion exchange process is used to remove undesirable ions from water and wastewater. The nitrogen removal process involves passing ammonia-laden wastewater downward through a series of columns packed with a naturally occurring zeolite called clinoptilolite. The clinoptilolite beds are usually four or five feet deep of 20 × 50 mesh particles. The ammonium ion adheres to or is absorbed by the clinoptilolite. When the first column in a series loses its ammonium ion adsorptive capacity, it is removed from the treatment scheme and washed with lime water. This step converts the captured ammonium ions to ammonia gas, which is then released to the atmosphere by contacting heated air with the wastewater stream, in much the same manner as described under ammonia stripping.

The clinoptilolite may also be regenerated by passing a brine or salt solution through the exchange bed. The sodium in the salt solution exchanges with the ammonium nitrogen. By removing the ammonium from the spent regenerant brine solution, the regenerant may be reused, thus eliminating the difficult problem of brine disposal.

6.15 Hyacinth Culture

There are two basic types of water hyacinth treatment systems. One system is based upon continual harvest of plants and the other is based upon minimal maintenance plant harvest. Hyacinth can be cultured in open basins year-round in frost-free areas. In colder climates, hyacinth can be grown seasonally in uncovered ponds and year-round in greenhouses. The continual harvest system relies primarily upon plant absorbtion of nutrients from the water. These systems are capable of removing ten to twenty pounds of nitrogen and phosphorus per acre per day and up to 100 pounds of carbon (organics or BOD) per acre per day in a properly designed and managed system. Effluent total nitrogen can be less than 1.5 mg/*L* and phosphorus below 0.2 mg/*L*.

A comparable amount of nutrients can be removed from secondary effluents in a greenhouse hyacinth culture system. In addition to absorption of nutrients by plants directly, bacteria and other organisms in the dense root mat of the plants treat the water by removing BOD and also nitrification/denitrification. A four to six-foot wide strip of plants along basin edges are removed approximately six times during the active growing season by using a modified hydraulic hay rake mounted on a backhoe. Extreme care must be exercised to keep hyacinth from reaching sensitive waters where they could create a nuisance for recreation and navigation activities.

6.16 Overland Flow

Overland flow systems are capable of producing a very high quality effluent. The wastewater to be treated is applied to grass-covered slips by sprinklers or to the land surface via ports in pipes at evenly spaced intervals. The water flows or trickles as sheet flow through water-tolerant grasses to a collection ditch. The microorganisms that live in the grass at the soil surface effectively reduce BOD and cause both nitrification and denitrification to occur. Heavy rainfall and runoff can cause an increase in solids in the effluent during the initial runoff from a storm.

6.2 NITRIFICATION

6.20 How Nitrification Is Accomplished

There are two bacteriological processes or steps which may occur simultaneously that produce the end result of nitrification.

1. *Conversion of ammonium to nitrite.* The first step in nitrification is the conversion of ammonium to nitrite. This is accomplished by a bacteria known as *Nitrosomonas*. *Nitrosomonas* use molecular free oxygen (O_2) in this conversion and therefore function only in an aerobic environment. The equation describing *Nitrosomonas* use of oxygen to break down ammonium (NH_4^+) into nitrite (NO_2^-) is:

$$NH_4^+ + 1.5O_2 \rightarrow 2H^+ + H_2O + NO_2^-$$

Note the hydrogen ion (H^+) production. The importance of this product will be discussed later in Section 6.222, Daily Operation, 1. Alkalinity.

2. *Conversion of nitrite to nitrate.* The second step in nitrification is the conversion of nitrite to nitrate. This is accomplished by *Nitrobacter* bacteria. *Nitrobacter* also require an aerobic environment with free oxygen. These bacteria use free oxygen to metabolize nitrite (NO_2^-) to nitrate (NO_3^-) as follows:

$$NO_2^- + 0.5O_2 \rightarrow NO_3^-$$

6.21 Equipment Necessary for Nitrification

Nitrification can be accomplished in either suspended growth reactors or attached growth reactors. In either case an ample amount of time is required for the process to develop the proper microbial population age as well as a sufficient quantity of oxygen. The necessary microbial age can be somewhat tricky in suspended growth reactors. Both processes must be operated to achieve complete nitrification by converting ammonium to nitrate. If the conversion only goes as far as nitrite, disinfection of the effluent can be very difficult.

1. *Suspended growth reactors.* A suspended growth reactor is normally an aeration basin. Aeration basins must be sized to allow the appropriate volume of mixed liquor, suspended solids concentration, influent wastewater flow and the addition of oxygen applied by aeration. The aeration basin must be large enough and the process operated in a fashion to produce an MCRT long enough (usually four days plus) to allow the nitrifying bacteria sufficient time to grow. Detention times must be at least four hours and preferably eight hours. Sufficient air supply must be available to maintain a dissolved oxygen level in the aeration basins between 1.5 and 4.0 mg/*L*.
2. *Fixed film reactors.* The two most common types of fixed film reactors are trickling filters and rotating biological contactors (RBC). In each case microorganisms grow on the media over which the wastewater is passed to accomplish the desired treatment. Oxygen is supplied to the microorganisms by either natural or forced draft air movement through the media. Proper operation requires sufficient media surface area to allow adequate contact time between the microorganisms and the wastewater to achieve the desired level of treatment. Proper treatment also requires an adequate supply of oxygen and sufficient pretreatment to reduce the applied BOD level. Recycling or recirculation of the reactor effluent is also important to achieve the desired degree of treatment.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

6.0A Algal growths are caused mainly by what two nutrients in receiving waters?

6.1A How is nitrogen removed by the nitrification/denitrification treatment process?

6.1B What is the recommended use of breakpoint chlorination for removing nitrogen?

6.1C How is ammonium nitrogen removed by the ion exchange process?

6.2A Nitrification can be accomplished by the use of what two types of biological growth reactors?

6.22 Operation

6.220 Nitrification Using Suspended Growth Reactors

Nitrification in a suspended growth reactor relies on two important factors: (1) sludge age or MCRT, and (2) available oxygen. The desired level of nitrification can be accomplished by allowing for a longer duration (4 to 8 hours) of activated sludge being aerated than is commonly found in a normally activated sludge secondary wastewater treatment facility. The MCRT should be greater than four days. Sufficient oxygen (1.5 to 4.0 mg/*L*) must be maintained in the reactor at all times so that free oxygen is available throughout the reactor where nitrification is taking place. Other factors include a low BOD and the proper bacteria present. Since nitrifying bacteria are relatively slow growers, they require a higher degree of treatment to survive. This is why step-feed aeration and contact stabilization reactors are not conducive to nitrification, but they can nitrify an effluent under certain conditions.

6.221 Suspended Growth Nitrification Processes

1. Conventional or Plug Flow Aeration Systems

This type of facility can lend itself well to a nitrification process because of the plug flow configuration and the detention time provided for the flow to pass through a long, narrow tank prior to the wastewater leaving the aeration tank. pH levels may drop during this detention time because nitrification destroys alkalinity. (See Section 6.222, "Daily Operation.")

2. Complete Mix Activated Sludge Process

A complete mix design provides a uniform mixture throughout the entire reactor so the problem of lack of oxygen dissolution within the reactor is lessened. However, this type of reactor may be more sensitive to a drop in alkalinity as ammonium is oxidized to nitrate. (See Section 6.222, "Daily Operation.")

3. Contact Stabilization

Because of the separately aerated return activated sludge used in contact stabilization, an insufficient number of nitrifying bacteria may be left in the biomass. Also the contact time for the wastewater being treated with the mixed liquor is insufficient to produce a high quality effluent. Therefore, contact stabilization plants are not ideal for the operation of a nitrification facility using a suspended growth reactor.

4. Extended Aeration

Extended aeration facilities can be well suited for use in nitrification due to the long aeration time for the mixed liquor.

5. Step-feed Aeration

Step-feed aeration can be used only for partial nitrification. Because of the addition of influent wastewater at several points along the aeration tank, the contact time for nitrogen conversion is insufficient for complete nitrification.

6.222 Daily Operation

1. Alkalinity

A problem associated with nitrification in suspended growth reactors is the hydrogen ion (H^+) production. The hydrogen uses the buffering capacity of the alkalinity in the wastewater such that a significant lowering of pH may occur and either affect the operation of downstream treatment processes or violate discharge requirements. The operator should keep calcium oxide (lime), soda ash, or other chemicals on hand for the purpose of increasing alkalinity, particularly at the end of a nitrifying aeration process.

2. Dissolved Oxygen

Dissolved oxygen levels must be maintained (preferably at 2.0 to 4.0 mg/*L*) throughout the aeration and nitrification processes. Areas within the aeration tank with less than about 0.2 mg/*L* dissolved oxygen may have significantly reduced nitrification due to the toxicity to the bacteria created by the lack of oxygen.

3. Nitrogen

Throughout the aeration tank, particularly at various key points along the reactor's length (if plug flow), operators need to measure various nitrogen compounds. Ammonium (NH_4^+) must be tested along with nitrite (NO_2^-) and nitrate (NO_3^-). These tests will enable the operator to determine the effectiveness of the nitrification process and to help determine if detention times and oxygen levels are sufficient for the desired results.

4. Temperature

The optimum wastewater temperature range is between 60 to 95 degrees F (15 to 35°C) for good nitrification operation. Nitrification is inhibited at low wastewater temperatures and up to five times as much detention time may be needed to accomplish "complete nitrification" in the winter as is needed in the summer. The growth rate of nitrifying bacteria increases as the wastewater temperature increases and conversely it decreases as the wastewater temperature decreases. Since there is no control over the wastewater temperature, operating compensations for slower winter growth rates are necessary. Increasing the MLVSS concentration, the MCRT, and adjusting the pH to favorable levels can be expected to provide substantial, if not "complete," oxidation of ammonia-nitrogen compounds. Under summer conditions, successful nitrification operation will be possible at less favorable pH levels and lower MLVSS concentrations.

5. Nitrogenous Food

The growth rate of nitrifying bacteria (*nitrosomonas* and *nitrobacter*) is affected very little by the organic load applied to the aeration system. However, the population of the nitrifying bacteria will be limited by the amount of nitrogenous food available in the wastewater. Organic nitrogen and phosphorus-containing compounds as well as many trace elements are essential to the growth of microorganisms in the aeration system. The generally recommended ratio of five-day BOD to nitrogen to phosphorus for domestic wastes is 100:5:1. Laboratory nitrogen determination (TKN) and phosphorus determination analysis should be performed so that you may add the supplemental phosphorus nutrient if necessary. Phosphorus in the form of phosphate fertilizer may be added and adjusted according to the five-day BOD level and the TKN concentration in the wastewater.

6. Actual Operation

The following operational information has been successful for one plant that has an aeration tank and clarifier for biological nitrification which is located after a conventional activated sludge process . The nitrification aeration tank is operated as a conventional plug flow system. MCRT values range between 14 to 18 days.

Dissolved oxygen levels are monitored closely to conserve energy and avoid wasting any DO. Target DO levels are 0.5 mg/*L* for the first five percent of the aeration tank length, 0.5 to 1.0 mg/*L* from five percent to 80 percent of the tank length and greater than 2.0 mg/*L* in the aeration tank effluent.

To achieve a good settling effluent, approximately 15 to 30 percent of the primary effluent (BOD around 40 to 50 mg/*L*) is bypassed to the nitrification aeration tank. This procedure not only helps with solids settling, but also facilitates sludge wasting. Before this procedure was instituted the solids were difficult to settle and it was difficult to waste sludge properly because any wasting error could be disastrous (not enough bugs remained or too many remained).

A highly nitrified effluent can be difficult to disinfect. If the nitrate levels fluctuate, the chlorine demand can change considerably during a very short time period. To correct this situation, approximately 1.5 mg/*L* of ammonia can be added to the effluent from the nitrification process. A chlorine dose of 12 mg/*L* of chlorine per each mg/*L* of ammonia is suggested. The ammonia will react with chlorine to form chloramines and an effectively disinfected effluent. The biological nitrification process is too sensitive and difficult to control to try to regulate and still have some ammonia in the effluent due to incomplete nitrification. Therefore a supplemental source of ammonia is necessary for effective disinfection. *NOTE:* The DO and MCRT numbers in this section differ slightly from recommended values in the chapter. This means that operators must develop optimum process control guidelines for their own facilities.

6.223 Attached Growth Nitrification Processes

Attached growth nitrification processes include the low-rate trickling filter process, rotating biological contactors and packed bed or packed tower reactors. In all of these processes aerobic conditions are essential for successful nitrification. Sufficient time is also necessary for the nitrifying bacteria to convert ammonia to nitrate.

6.224 Equipment Necessary to Operate an Attached Growth Nitrification Process

An attached growth (fixed film) reactor constructed in the shape of a trickling filter must have vessel containment and the appropriate media surface area for zoogleal mass and bacteriological action to take place. Modern reactors use plastic media in place of rocks or wood slats. Plastic media can provide a great deal of surface area for interaction of bacteria, wastewater, and air which results in the conversion of ammonium to nitrate.

The trickling filter type of reactor can be provided with either natural or forced ventilation. Blowers or fans can provide the forced ventilation from the bottom to the top of the reactor. As the liquid flows through the media from the top, air is forced up through the media and water trickling downward, thereby causing a cross-flow of wastewater and oxygen.

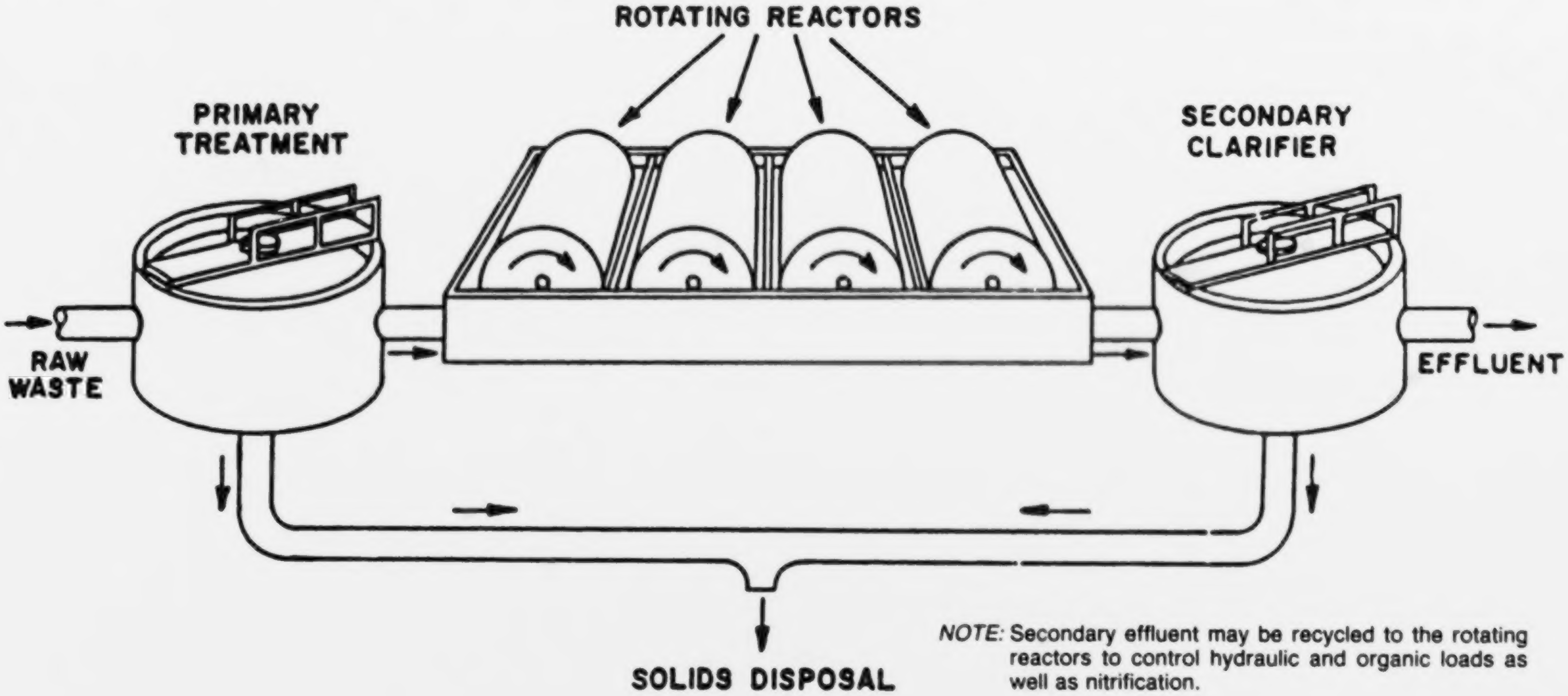
For trickling filters to nitrify the wastewater being treated, the BOD must be very low. This is achieved by using two-stage trickling filters or rotating biological contactors operated in series with nitrification occurring in the last contactors.

2. Pumps and Distribution Arms

The success of attached growth or packed tower (tall trickling filters with synthetic media) nitrification relies on a constant supply of influent and recycled wastewater trickling over the bacteriological growths on the fixed medium. Wastewater is pumped to the top of the nitrification towers where distribution arms allow an equal or even distribution of flow over the entire surface of the media. Normally nitrification towers using the fixed media concept are circular, thereby providing for continuous clockwise motion of distribution arms using the water pressure developed by pumps. Recirculation is provided to allow for a constant and even distribution of the wastewater over the entire surface media. Recirculation also dilutes the primary effluent applied to the filter, returns microorganisms to treat wastes, equalizes food (BOD) loading to microorganisms on media, and provides oxygen for the microorganisms. During low flow conditions, the recycle will have the beneficial effect of allowing for a constant flow and organic loading capacity. Normally a wet well is provided from which the effluent is pumped to the top of the nitrification towers to the distributors. These wet wells provide constant head conditions for the recirculation pumps.

6.225 Rotating Biological Contactors (Figure 6.1)

Rotating biological contactors (RBC) have a rotating "shaft" surrounded by plastic discs called the "media." The


ROTATING REACTORS
PRIMARY TREATMENT
SECONDARY CLARIFIER
RAW WASTE
EFFLUENT
SOLIDS DISPOSAL

NOTE: Secondary effluent may be recycled to the rotating reactors to control hydraulic and organic loads as well as nitrification.

Fig. 6.1 Rotating biological contactors capable of providing for conversion of ammonia nitrogen to nitrate nitrogen

shaft and media are called the "drum." The plastic-disc media are made of high-density plastic circular sheets usually 12 feet in diameter. These sheets are bonded and assembled onto horizontal shafts up to 25 feet in length. Spacing between the sheets provides the hollow (void) space for distribution of wastewater and air.

A biological slime (*ZOOGLEAL MASS*[1]) grows on the media when conditions are suitable. This process is very similar to a trickling filter where the biological slime grows on rock or other media and settled wastewater (primary effluent) is applied over the media. With rotating biological contactors, the biological slime grows on the surface of the plastic-disc media. The slime is rotated into the settled wastewater and then into the atmosphere to provide oxygen for the microorganisms.

Rotating biological contactors provide a surface for the growth of bacteria and use of food in the wastewater for conversion of ammonium nitrogen to nitrate. Oxygen is supplied using natural air convection or ventilation.

Nitrification using a rotating biological contactor is monitored in much the same way as was discussed in the previous section on suspended growth reactors. It is important to monitor oxygen levels, nitrogen levels and alkalinity throughout the flow stream through the reactors. Nitrification takes place in the last stage or final contactor in a series of contactors.

6.226 Operation of Attached Growth Nitrification Processes (Figures 6.2, 6.3, 6.4 and 6.5)

1. Wastewater Flow

The wastewater application rate to the surface of an attached growth nitrification process must be no more than as specified under the design criteria in terms of gallons per day per square foot of media. A flow in excess of design criteria may cause a hydraulic sloughing or washing off of the film with the valuable zoogleal growth that provides for the desired treatment and nitrification. If flow is substantially less than recommended for the application rates of wastewater to the surface of the reactor, death or dormancy of organisms may result due to lack of food, oxygen or drying out of the growth, thus hindering treatment and causing an incomplete nitrification reaction.

2. Waste Loads

Waste loads should also be within the range of design criteria. BOD loadings must be fairly uniform over the surface for good performance. To achieve the desired level of nitrification, ammonia loadings must be within expected levels. The ratio of five-day BOD to nitrogen to phosphorus should be approximately 100:5:1. Laboratory nitrogen determination (TKN) and phosphorus determination analysis should be performed so that supplemental phosphorus nutrient may be added if necessary.

3. Oxygen Transfer

Oxygen transfer is important in order to accomplish the desired nitrification results. The oxygen must be measured in the wastewater applied to and flowing from attached growth nitrification processes to determine if at least one to two mg/*L* of oxygen are in solution at all times. If oxygen levels become too low, there will not be sufficient oxygen for conversion of ammonium nitrogen to nitrate by the bacteria on the media. In addition, low dissolved oxygen levels may result in the slowing down or dormancy of the organisms, thereby reducing process efficiency.

4. Daily Operation

a. Temperature Variations

Fixed film reactors can be adversely affected by low temperatures causing freezing or other process efficiency complications. If the ambient air is too cold, frost or ice may develop on the media thereby reducing the efficiency of the process and potentially causing mechanical problems should the ice load become heavy or cause additional weight on one side of the reactor.

Nitrification bacteria tend to slow down and become inactive when wastewater temperatures drop below 50°F (10°C). Wastewater temperature may be controlled by adjusting the recycling rate.

b. Sloughing of Organisms

A trickling filter type attached growth nitrification process can allow for a certain amount of sloughing of zoogleal mass. These microorganisms are dead or flushed off the media and then become part of the effluent, thus increasing the effluent suspended solids. These additional suspended solids must be removed by the treatment plant's final clarifiers prior to any discharge to receiving waters.

c. Oxygen and Flow Variations

Since the success of nitrification through an attached growth nitrification process is dependent on a constant wastewater flow and the appropriate oxygen levels, it is important that these two elements be monitored closely. Other important factors requiring monitoring include influent BOD (should be low) and ammonia and also proper recirculation or recycle rates.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

6.2B How can the alkalinity be sustained in a nitrification process?

6.2C What tests must be conducted at various key points along the reactors during the nitrification process?

6.2D How is oxygen provided in attached growth nitrification processes?

6.2E Why must the wastewater flow be distributed over the surface of a nitrification tower at an optimum rate?

6.2F What two items must be monitored closely by operators of attached growth nitrification processes?

---

[1] *Zoogleal Mass (ZOE-glee-al). A complex population of organisms that form a "slime growth" on the trickling filter or packed tower media. These organisms break down the organic matter and convert ammonia to nitrate in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt and other debris. "Slime growth" is more commonly used.*

Fig. 6.2 Packed tower for nitrification process

Fig. 6.3 Blowers for forced ventilation into packed towers

Fig. 6.4 Plastic media used for "trickling filter" type nitrification

Fig. 6.5 Fully packed tower of plastic media used for nitrification

6.3 DENITRIFICATION

6.30 How Denitrification Is Accomplished in Wastewater

Nitrate will be reduced to nitrogen gas by certain types of microorganisms under appropriate environmental conditions. This process, known as "denitrification" is accomplished by several species of heterotrophic bacteria metabolizing the nitrate to obtain oxygen, thus releasing nitrogen gas as a waste product.

6.31 Equipment Necessary for Denitrification

Bacterial metabolic denitrification requires an environment void of free oxygen. In the absence of free oxygen, the bacteria will be forced to obtain the oxygen necessary for cell metabolism from the nitrate ion. This process is called endogenous respiration.

1. Attached Growth (Fixed Film) Reactors

Most denitrification processes use submerged media columns wherein the voids are filled with the wastewater being denitrified. The varieties of media upon which the denitrifying bacteria are attached include packed beds with high porosity corrugated sheet modules or low porosity fine media and fluidized beds with high porosity fine media, such as sand. In a fluidized bed, sand becomes the fixed film on which organisms can attach.

2. Suspended Growth Reactors

Under ideal circumstances a suspended growth reactor similar to an aeration basin used in the activated sludge process can be allowed to operate without oxygen or air being introduced. The suspended growth reactor may be a portion of an existing aeration basin or a separate reaction chamber set aside for the purpose of denitrification. An anaerobic environment can be produced to provide the conditions conducive for bacterial reduction of nitrate to nitrogen gas.

6.32 Operation

6.320 Denitrification Operation in a Fixed Film Reactor

In the biological fluidized bed process (Figures 6.6 and 6.7), wastewater flows upward through a bed of fine sand at a velocity sufficient for the sand to float or "fluidize." This action allows for the entire surface area of the sand to be available for biological growth. As the wastewater flows into the reactor and the sand is "fluidized," oxygen levels are carefully monitored to be certain that no free oxygen exists within the reaction chamber.

In the fixed film reactor, a carbon food source is added to allow for biological metabolism. This food source can be methanol (wood alcohol), methane gas, primary effluent, or other sources of high carbon food to stimulate biological growth. The bacteria (which are attached to the fixed media) feed on the carbon source and must derive oxygen from the nitrate ion for the breakdown of the food and the absorption into the bacterial cell structure. The bacteria will break down the ion using the oxygen in the metabolic process and releasing the nitrogen as a gas. If primary effluent is used as a carbon food source, the organic and ammonia nitrogen in the primary effluent will not be removed.

6.321 Suspended Growth Reactors (Figures 6.8 and 6.9)

1. Denitrification Using Suspended Growth Reactors

A suspended growth media can provide an environment for anaerobic bacteria that will break down nitrate into nitrogen gas and the oxygen used for metabolism. Wastewater is allowed to flow through a vessel without free oxygen, but with a carbon food source as the necessary component for the appropriate denitrification metabolism to take place. Just as in the operation of a fixed film reactor, organisms feed on the organic carbon source and if no free oxygen is available will break down the nitrate ion using the oxygen portion of that nitrogen ion and releasing the nitrogen as a gas.

Figure 6.9 shows three types of nitrification/denitrification suspended growth reactors.

1. *Separate Sludge Post-DN.* BOD removal and nitrification occur in the first aeration basin reactor. An organic carbon food source is added to the second reactor where denitrification takes place.

2. *Single Sludge Post-DN.* BOD removal and nitrification occur in the first reactor and the wastewater being treated flows directly into the second reactor for denitrification without an intermediate clarifier.

3. *Single Sludge Pre-DN.* A food source is added to the anaerobic first reactor where denitrification occurs. The wastewater then flows directly to the next reactor (an aeration basin) for nitrification. The recirculated flow returns the nitrate ions to the influent to the first reactor for denitrification.

6.322 Daily Operation

1. Carbon Source Feed Control

The carbon source (particularly in the case of fixed film reactors) must be regulated carefully so that an adequate supply of the carbon food source is provided for the metabolic process and the breakdown of the nitrate into nitrogen gas and usable oxygen. If too much of the carbon (organic) is fed into the process, the result can be an increase in the effluent BOD, COD or TOC levels (Biochemical Oxygen Demand, Chemical Oxygen Demand, or Total Organic Carbon). This result is not desirable and may lead to violations of BOD and/or COD effluent requirements.

2. Control of Free Oxygen

The availability of free oxygen in either a suspended growth denitrification reactor or a fixed media denitrification reactor will reduce the efficiency of the process. Special care must be taken to avoid agitation of the wastewater or any other possibility of allowing for oxygen to enter the process flow stream.

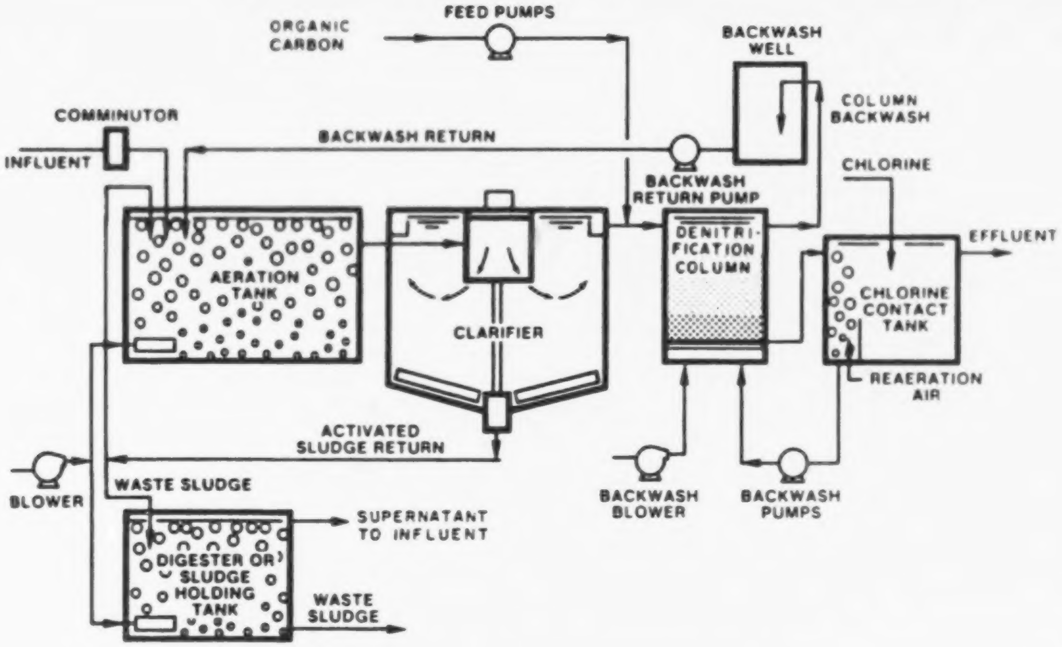

ORGANIC CARBON
FEED PUMPS
BACKWASH WELL
COLUMN BACKWASH
COMMINUTOR
BACKWASH RETURN
INFLUENT
BACKWASH RETURN PUMP
CHLORINE
EFFLUENT
AERATION TANK
DENITRIFICATION COLUMN
CHLORINE CONTACT TANK
CLARIFIER
REAERATION AIR
ACTIVATED SLUDGE RETURN
BLOWER
WASTE SLUDGE
BACKWASH BLOWER
BACKWASH PUMPS
SUPERNATANT TO INFLUENT
DIGESTER OR SLUDGE HOLDING TANK
WASTE SLUDGE

Fig. 6.6 Nitrification-denitrification flow sheet using low porosity fine media in denitrification column

(from *Process Design Manual for Nitrogen Control*, U.S. Environmental Protection Agency)

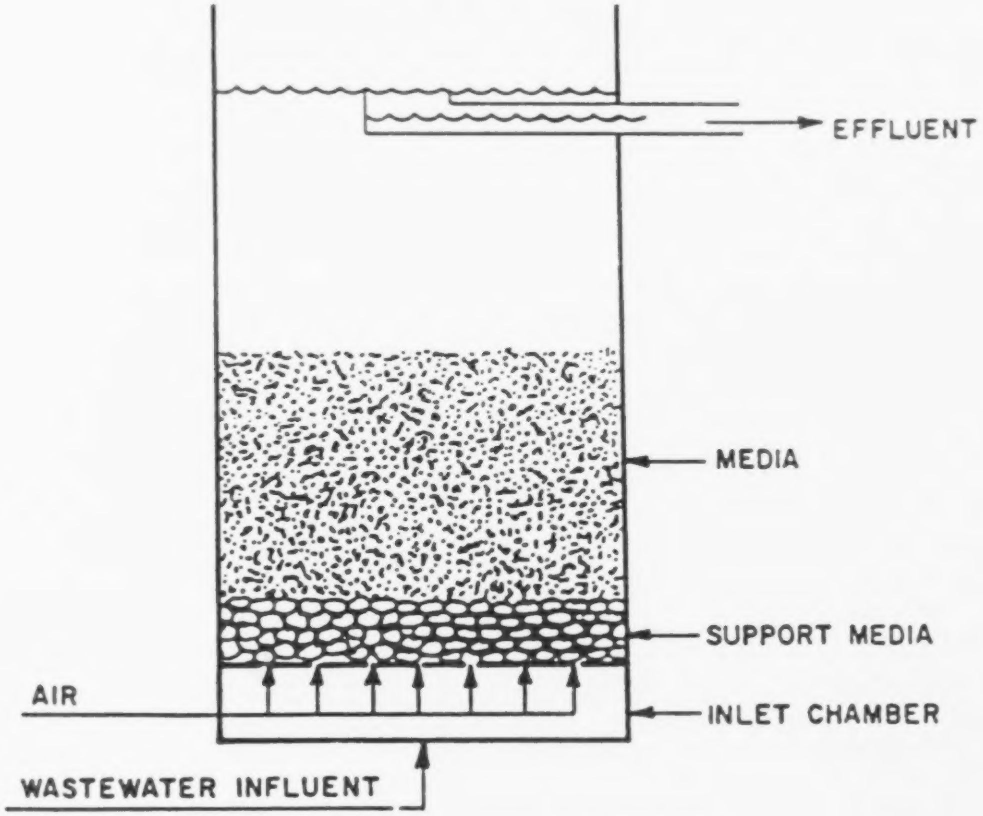
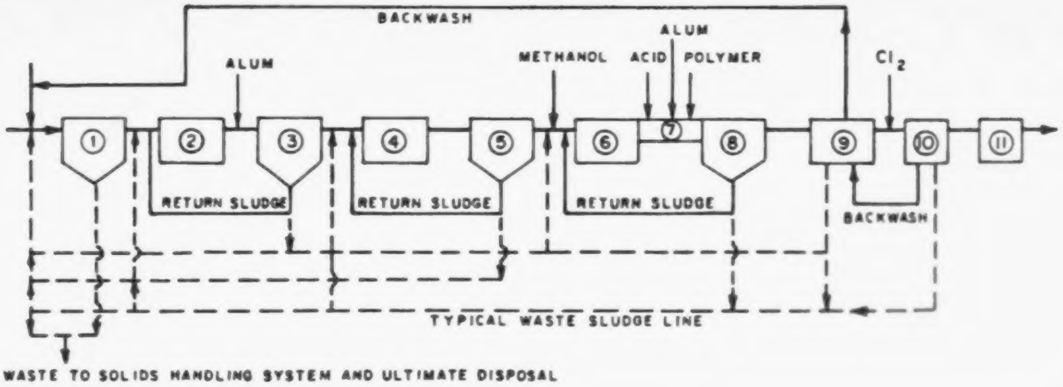

EFFLUENT
MEDIA
SUPPORT MEDIA
AIR
INLET CHAMBER
WASTEWATER INFLUENT

Fig. 6.7 Schematic diagram of fluidized bed used for biological denitrification



PRIMARY TREATMENT	HIGH RATE ACTIVATED SLUDGE	NITRIFYING ACTIVATED SLUDGE	DENITRIFYING ACTIVATED SLUDGE	POST TREATMENT
① SEDIMENTATION TANK	② AERATION TANK ③ SEDIMENTATION TANK	④ AERATION TANK ⑤ SEDIMENTATION TANK	⑥ ANOXIC REACTORS ⑦ AERATED CHANNEL ⑧ SEDIMENTATION TANK	⑨ MIXED MEDIA FILTERS ⑩ CHLORINE CONTACT ⑪ POST AERATION

Fig. 6.8 Nitrification-denitrification flow sheet using modifications of the activated sludge process

(from *Process Design Manual for Nitrogen Control*, U.S. Environmental Protection Agency)

3. Control of Effluent Suspended Solids

Suspended solids in the effluent from suspended growth denitrifying reactors and sedimentation tanks can be removed by mixed media filters. See Chapter 4, "Solids Removal from Secondary Effluents," for processes and O & M procedures for removal of suspended solids.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

6.3A What kind of environment is necessary for denitrification?

6.3B What is the purpose of sand in a fluidized bed reactor?

6.3C List the two kinds of reactors used in denitrification and give an example of a common type of each reactor.

6.3D What will happen if free oxygen is present in the denitrification process?

6.4 AMMONIA STRIPPING

6.40 How Ammonia Is Stripped from Wastewater

The ammonia stripping process is a reliable means of ammonia removal under suitable environmental conditions. The equilibrium equation for ammonia in water is as follows:

$$\begin{array}{ccccc} NH_4^+ & \rightleftharpoons & NH_3 & + & H^+ \\ \text{Ammonium Ion} & & \text{Ammonia Gas} & & \text{Hydrogen Ion} \end{array}$$

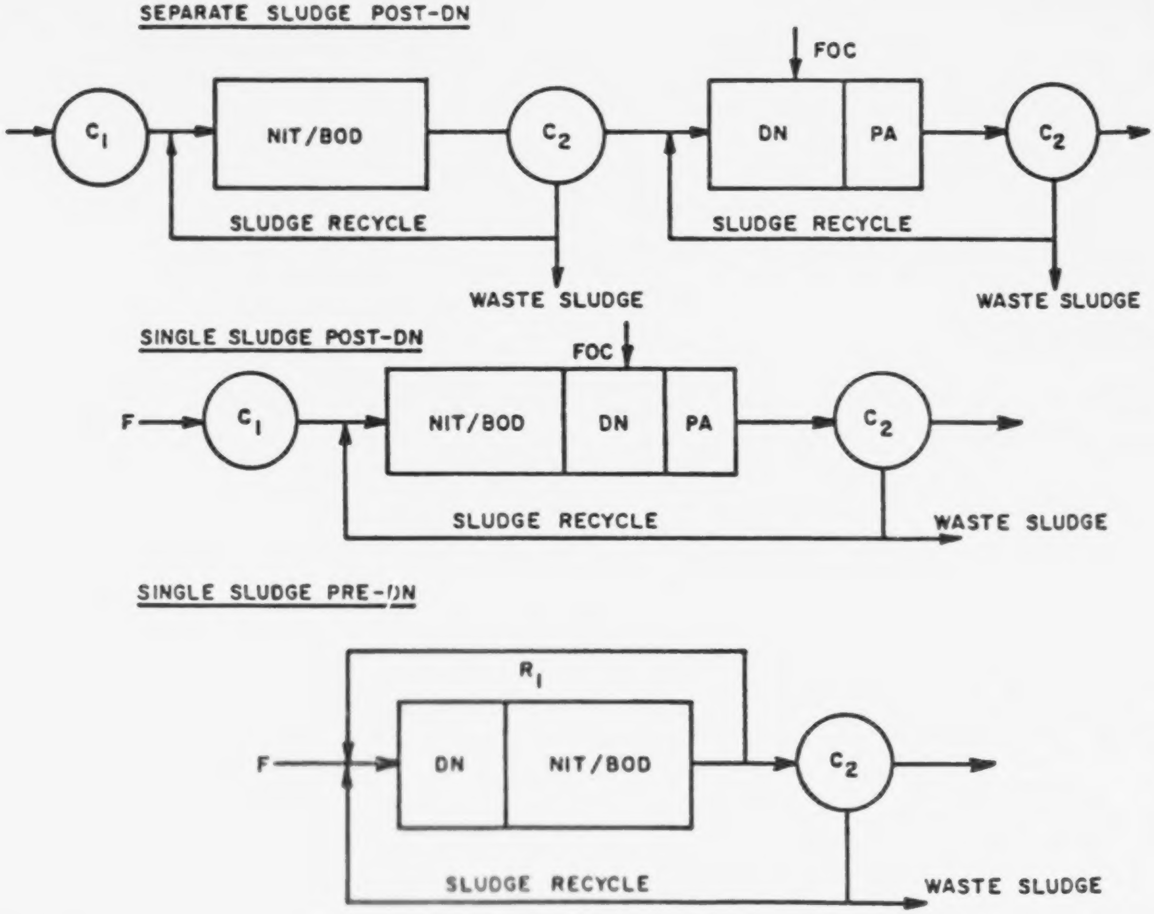
At normal temperatures and a pH of 7, the reaction is shifted almost completely to the left. Therefore, only ammonium ions are present and virtually no dissolved ammonia gas. When the pH increases above 7 (Figure 6.10), the reaction shifts to the right, and the portion of dissolved ammonia gas increases until at pH levels of 10.5 to 11.5, almost all of the ammonium ion is converted to dissolved ammonia gas. This ammonia gas may be removed by the ammonia stripping process.

The ammonia stripping process (Figure 6.11) requires the pH of the wastewater to be raised to a level of 10.8 to 11.5, the breaking up of water droplets in the stripping process to release the ammonia gas, and the removal of the ammonia gas from the stripping tower by the movement of large quantities of air through the tower.

6.41 Equipment Necessary for Ammonia Stripping

1. A High pH Source

In order to increase the pH of the wastewater, a chemical such as calcium oxide or lime must be added to the wastewater. Lime silos, slaking equipment, lime feeders, and flash mixing chambers are all necessary to allow for the


SEPARATE SLUDGE POST-DN
FOC
C_1
NIT/BOD
C_2
DN
PA
C_2
SLUDGE RECYCLE
SLUDGE RECYCLE
WASTE SLUDGE
WASTE SLUDGE
SINGLE SLUDGE POST-DN
FOC
F
C_1
NIT/BOD
DN
PA
C_2
SLUDGE RECYCLE
WASTE SLUDGE
SINGLE SLUDGE PRE-DN
R_1
F
DN
NIT/BOD
C_2
SLUDGE RECYCLE
WASTE SLUDGE

Legend

C_1	Clarifier 1 or Primary	PA	Phosphorus Removal
C_2	Clarifier 2 or Secondary	F	Food Source
DN	Denitrification	R_1	Recirculation
NIT/BOD	Nitrification and BOD Removal		

Fig. 6.9 Nitrification and denitrification using suspended growth reactors

introduction of lime into the wastewater and for the mixing to properly increase the pH to between 10.5 and 11.5. (See equipment listing and operation in Chapter 5, "Phosphorus Removal," for additional information.)

2. Pumps and Piping

Most air stripping takes place using packed media towers and therefore high pH wastewater must be pumped to the top of these towers to allow for the water to fall, the droplets to break up and for air contact with the wastewater.

3. Tower and Media

A tower filled with wood or plastic media or a tank filled with media must be provided for the wastewater (at a high pH) to flow or trickle through. The splashing or breaking up of the water droplets allows for the release of the ammonia gas and this gas is removed from the tower by large quantities of air moving through the tower.

6.42 Operation

1. Lime Feed (Figure 6.11)

Lime feed is accomplished normally by mixing quicklime (calcium oxide) with water and feeding the solution to the wastewater. A sufficient amount of lime must be applied to allow for the wastewater pH to be increased to at least 10.5 and preferably above 11.2. By increasing the pH to these levels, ammonia gas will be produced which can then be removed by the air stripping process.

2. Pumping of Wastewater

The more contact the wastewater has with the air after the pH of the wastewater has been increased, the higher the removal efficiency of ammonia gas. Large capacity pumps are necessary to recycle the high pH wastewater through the packed tower media.

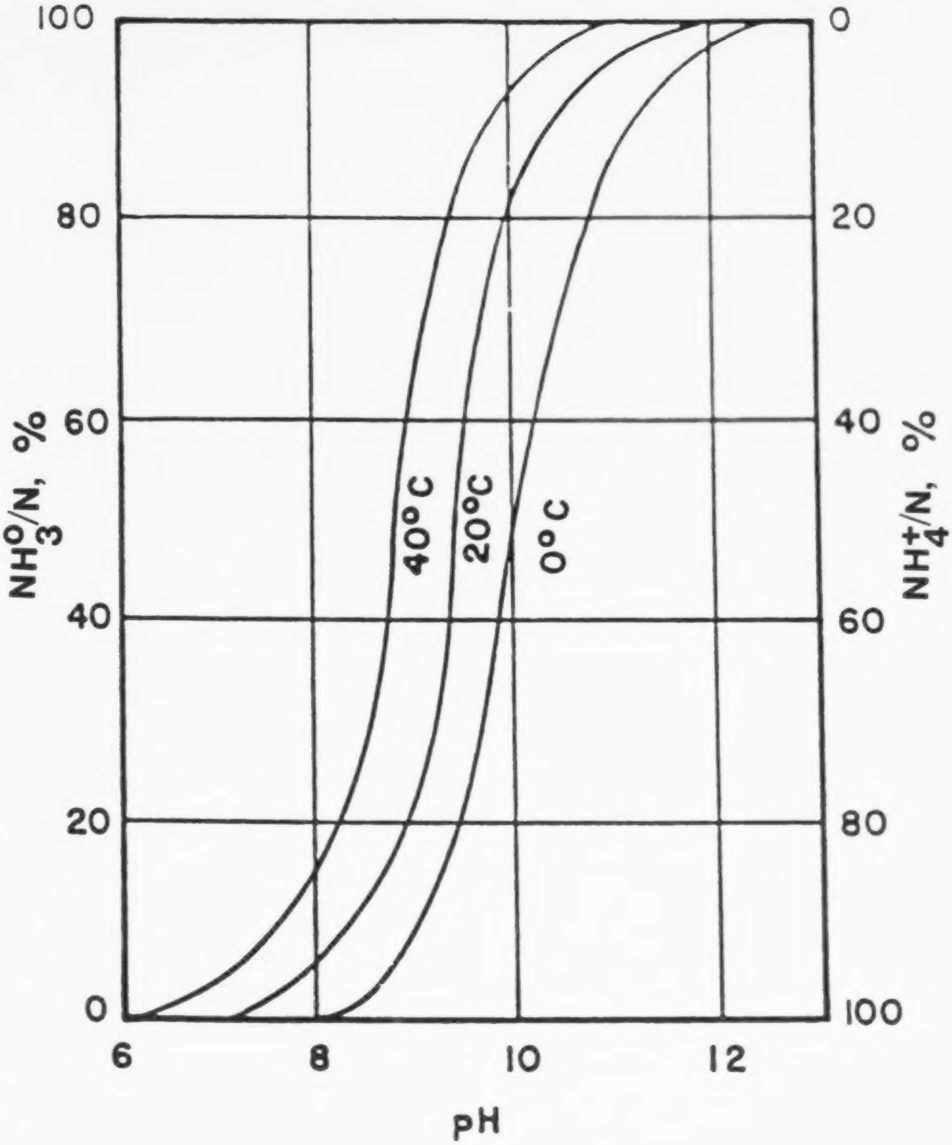


Fig. 6.10 Effects of pH and temperature on equilibrium between ammonium ion (NH_4^+) and ammonia gas ($NH_3°$)

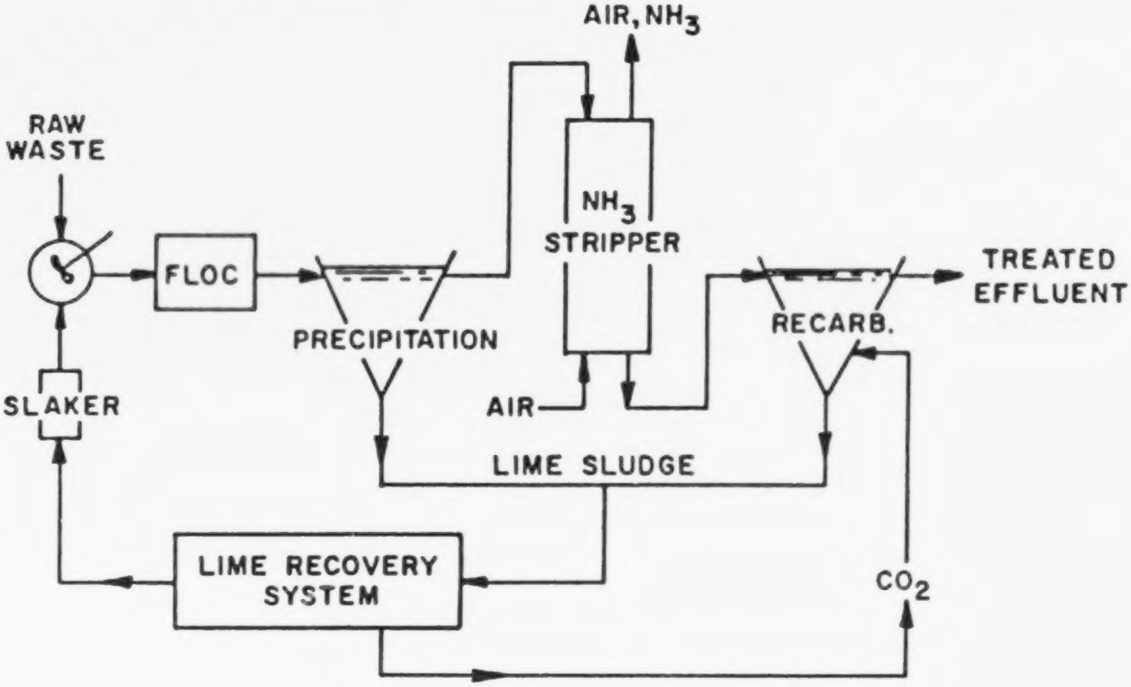


Fig. 6.11 Schematic of ammonia stripping process with lime recovery

6.43 Troubleshooting

1. Calcium Carbonate Scale

Calcium carbonate is formed when the carbon dioxide in the atmosphere combines with calcium oxide to produce limestone (calcium carbonate scale). The scale can adversely affect the pumping capabilities and can close off the interior walls of pipes, pumps and channels. Calcium carbonate can fill the voids of packed media, thereby reducing the efficiency of the ammonia stripping process. Scale must be cleaned with muriatic acid or hot water on a routine basis to maintain pumps, piping and other stripping equipment including media packaging.

2. Freezing

Because of the high air flow and the amount of water pumped for contact with the air stripping process, the cooling effect can cause freezing temperatures within the packed media tower thereby reducing the efficiency of the process. Cold temperatures also reduce the capability of the reaction to convert ammonium ion to ammonia gas. As cold temperatures reduce the gas production capability, additional calcium oxide must be added to compensate. This further complicates problems from the standpoint of calcium carbonate scale formation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

6.4A What environmental conditions are important for a successful ammonia stripping process?

6.4B List two operating problems of the air stripping process.

6.4C How is calcium carbonate scale formed during the air stripping process?

6.4D How can calcium carbonate scale be removed?

6.5 BREAKPOINT CHLORINATION (Figure 6.12)

6.50 How Does Breakpoint Chlorination Remove Nitrogen?

When chlorine is added to water the chlorine first reacts with the inorganic reducing materials such as hydrogen sulfide. These reactions with inorganic reducing materials occur before any chlorine residual occurs. Ferrous iron, manganese, and nitrite are examples of other inorganic reducing agents that react with chlorine and reduce the chlorine to chloride.

When chlorine is added to waters containing ammonia, the ammonia reacts with hypochlorous acid (HOCl) to form monochloramine, dichloramine and trichloramine (Zone 1 in Figure 6.12). The formation of these chloramines depends on the pH of the solution and the initial chlorine-ammonia ratio. If enough chlorine is added to react with the inorganic compounds and nitrogenous compounds, then this chlorine will react with organic matter to produce chlororganic compounds and other combined forms of chlorine.

Addition of more chlorine results in the destruction of chloramines and chlororganic compounds. The oxidation of these compounds produces nitrous oxide (N_2O), nitrogen gas (N_2) and chlorine (Zone 2 in Figure 6.12). Therefore, if enough chlorine is added to wastewater containing ammonia nitrogen, the complete oxidation of ammonia nitrogen will occur at the "breakpoint." Then if any additional chlorine

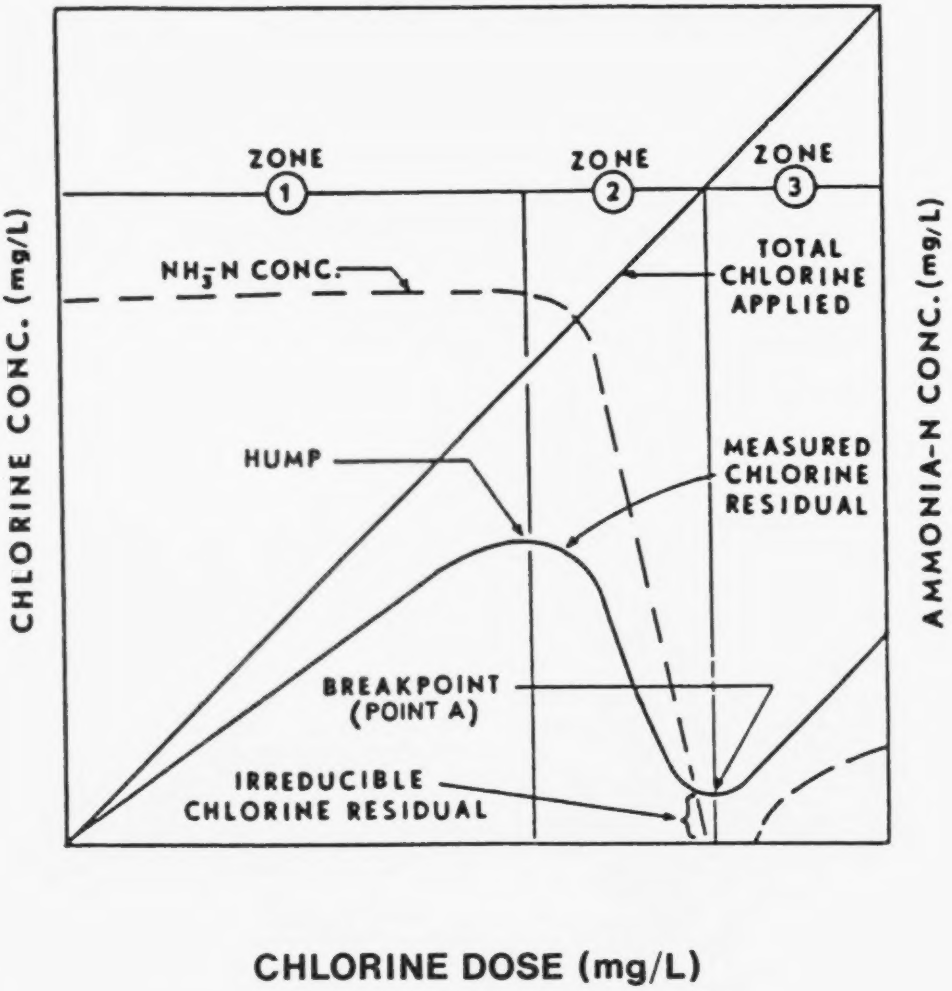


Fig. 6.12 Typical breakpoint chlorination reaction curve illustrating destruction of the ammonia molecule

(from *Process Design Manual for Nitrogen Control*, U.S. Environmental Protection Agency) is added beyond the breakpoint, the chlorine will exist as free available chlorine (Zone 3 in Figure 6.12).

6.51 Equipment Necessary for Breakpoint Chlorination

1. Chlorine Feed Equipment

Adequate chlorine feed equipment is necessary to provide the appropriate quantity of chlorine in relationship to the amount of ammonia nitrogen to be reduced in the effluent under peak flow conditions. Approximately 10 mg/*L* of chlorine is required per mg/*L* of ammonium plus additional chlorine to react with the inorganic reducing materials and organic compounds.

2. Reaction Chamber

Although the reaction between chlorine and ammonia nitrogen is quite fast, the appropriate flash mixing chamber and detention time must be allowed for in a reaction vessel dedicated to breakpoint chlorination.

6.52 Operation

1. Chlorine Feed and Dose

Chlorine is fed to wastewater containing ammonium nitrogen at a sufficient rate to provide enough chlorine to oxidize the desired amount of ammonia nitrogen. A reaction requirement of 10 parts of chlorine to 1 part of ammonium nitrogen is considered necessary to reach or pass the "breakpoint."

2. Secondary or Filtered Effluent

The breakpoint chlorination process is most efficient in treating an effluent containing low suspended solids, low BOD and a low chlorine demand. Using secondary or a filtered effluent, the chlorine can work on the ammonia nitrogen instead of being tied up in oxidation reactions with organic matter, reducing materials and other chemicals. Filtered waters are more desirable than secondary effluent for breakpoint chlorination.

3. Final Clean Up

Breakpoint chlorination is frequently used as final clean up following other nitrogen removal processes. When treating a high quality effluent, relatively small amounts of chlorine are needed to remove the remaining nitrogen.

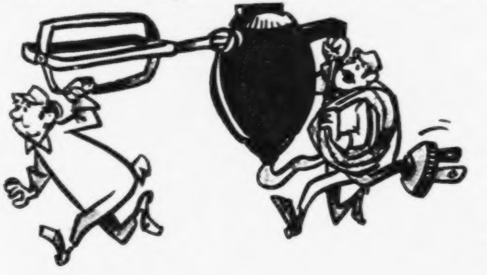
6.53 Daily Operation

1. Contact Time

The appropriate contact time required to oxidize ammonia nitrogen with chlorine varies anywhere from five to fifteen minutes depending on the wastewater characteristics. The higher the quality of wastewater, the shorter the required contact time.

2. Flash Mixing

It is important that chlorine mixing with the wastewater be instantaneous and complete. A flash mix or other rapid mixing basin must be used to accomplish complete mixing and thereby maximize process efficiency.



6.54 Careful Control of Chlorine Feed

All wastewaters vary; however, an approximate ratio of 10 parts of chlorine to 1 part of ammonia nitrogen is normally required for a complete breakpoint reaction to occur. If less chlorine is used, free residual chlorine and chloramine or dichloramine compounds will remain in solution and ammonia nitrogen will not be properly removed. If there is excess chlorine in the plant effluent, this residual can be hazardous to aquatic life. Thus effluents should be dechlorinated to protect aquatic life. Also if too much chlorine is added, the pH could be too low and require the addition of a basic chemical to increase the pH to an acceptable level for discharge.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

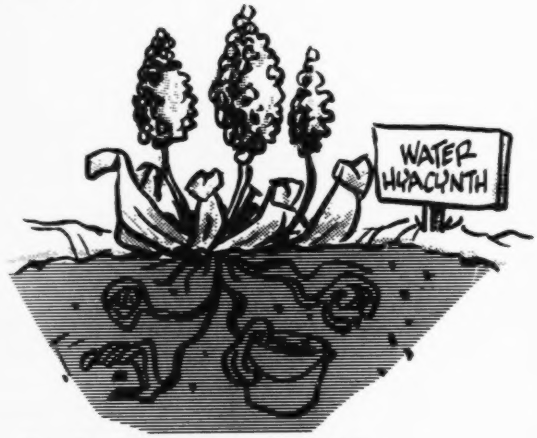
6.5A Describe the breakpoint chlorination process

6.5B What is the appropriate application for breakpoint chlorination?

6.6 HYACINTH CULTURE

6.60 Waste Treatment

Water hyacinth cultures have been used to successfully treat both municipal and industrial wastewaters. Municipalities have used hyacinth cultures to remove residual organics (BOD), suspended solids, nitrogen and phosphorus. Industry has used hyacinth cultures for removal of a variety of toxic chemicals, heavy metals and nutrients from many types of wastewaters. Hazardous materials must be removed in the first of a series of hyacinth ponds and the contaminated hyacinths must be harvested from the ponds and processed for ultimate disposal through digestion or composting.



6.61 How the Treatment Process Works

Water hyacinth cultures float on the surface of the water being treated. The roots of the plant extend down into the water to about a foot below the surface where they absorb nutrients (nitrogen, phosphorus and carbon or organics) directly from the water. However, the main nitrogen-removal mechanism is bacterial nitrification/denitrification. When hyacinth plant stands have reached maximum density, plant uptake of nitrogen is minimal. These systems are capable of removing ten to twenty pounds of nitrogen per acre per day and up to 100 pounds of BOD per acre per day in a properly designed and operated treatment system. The effluent nitrogen concentration can be less than 1.5 mg/*L* and phosphorus below 0.2 mg/*L*.

Hyacinth systems are responsible for a significant removal of the nutrients, nitrogen and phosphorus. Bacterial populations thriving in the plant's root system oxidize biologically degradable compounds as well as oxidize and reduce nitrogen forms. In the anaerobic zones of the roots and in basin sediment, denitrifying bacteria convert oxidized inorganic nitrogen to gaseous molecular nitrogen, which can then be lost to the atmosphere.

Many invertebrates such as amphipods, insect larvae, and molluscs further enhance the process by removing particulate matter from the water being treated. These organisms are in turn preyed upon by various vertebrate populations including fish, birds, amphibians, and reptiles.

Harvesting can be accomplished by the use of a water tractor in a continual harvest type of hyacinth culture system. This tractor floats on top of the hyacinth crop, conditioning and separating the matted hyacinth plants and strategically maneuvering them to a shore-based harvester/processor which chops and pumps the plant material as a liquid slurry product.

6.62 Operation

Similar to other biological treatment processes, treatment rates in water hyacinth systems depend on temperature. However, unlike most other biological systems not only does temperature affect the activity of the bacteria in the root zone, but also the vitality of the water hyacinth plant. Both air and water temperature are important in evaluating plant vitality. Water hyacinth are a tropical plant and thus do not survive in cooler climates.

Therefore, hyacinth cultures can treat wastewaters only in frost-free areas or during frost-free seasons. Installation of a commercial greenhouse (Figure 6.13) covered with translucent plastic will allow year-round operation of a minimal harvest hyacinth system. The greenhouse should be provided with automatic ridge vents and appropriate venting along the bottom of the sidewalls. Proper venting is desirable in the summer to expel excess heat and in the winter to retain heat.

Conventional hyacinth basins are quite inefficient. The root mat zone, which is only six to twelve inches deep, provides most of the aerobic treatment. The anaerobic organic sediment zone is also very important for storing nutrients and enhancing denitrification. Most of the sedimentation and treatment occurs in the upstream portion of a hyacinth basin, with the remainder of the basin only "polishing" the water. In a three-foot deep basin most of the waters never come in contact with the root mat. Recirculation, upwelling and aeration have been evaluated as a means to bring water into contact with biota in the root mat. Such approaches destroy the sediment layer and are only slightly successful in "forcing" water into or through the dense mat of roots.

There should be multiple hyacinth basins with the capacity to treat the design flow when one basin is out of service. The average water depth should not be greater than 36 inches. Multiple surface inlets and outlets should distribute the flow uniformly throughout each basin. This may be accomplished by weirs, openings in a baffle or by a perforated pipe. The size of the basins should be one acre or less. The bottom of each basin must be sloped to facilitate draining. A surge basin for flow equalization or some other method of flow equalization to each basin is desirable.

A fixed barrier is installed at the outlet to retain hyacinth and to create a clear water zone. Screening may be used as a barrier material, but a permeable rock barrier is preferred to prevent hyacinth from escaping to receiving waters. The water depth in the outlet area should be less than 24 inches. The bottom of the outlet area is covered by a layer of broken rock or washed gravel.

The organic loading for each hyacinth basin should not exceed 100 pounds of BOD per acre per day unless supplemental aeration is provided to consistently maintain an

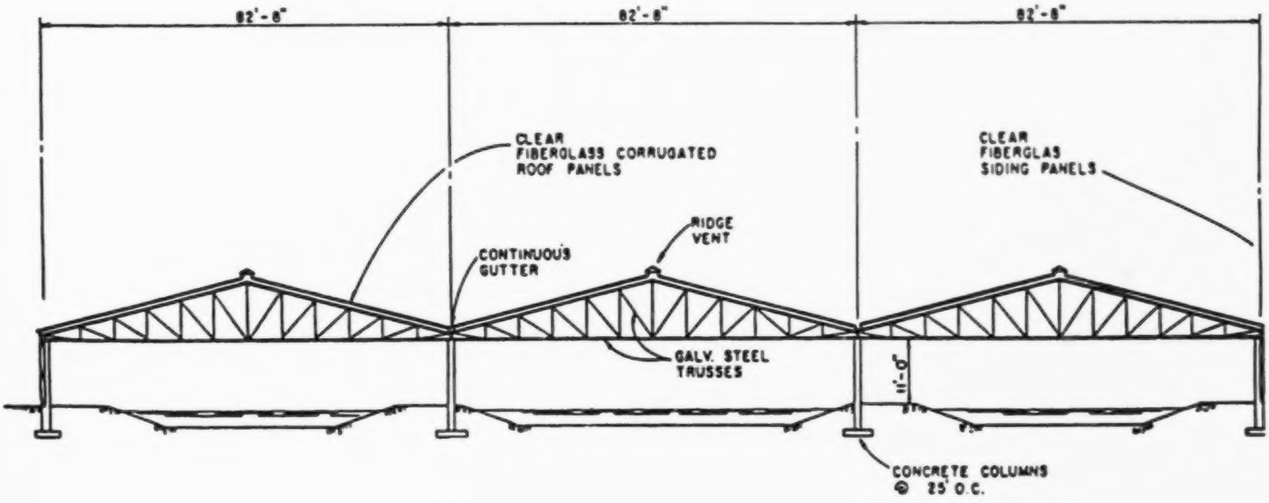

82'-8"
82'-8"
82'-8"
CLEAR FIBERGLASS CORRUGATED ROOF PANELS
CLEAR FIBERGLAS SIDING PANELS
RIDGE VENT
CONTINUOUS GUTTER
GALV. STEEL TRUSSES
11'-0"
CONCRETE COLUMNS @ 25' O.C.

Fig. 6.13 Greenhouse of hyacinth culture

aerobic surface water layer. The maximum hydraulic loading should not exceed 0.20 MGD per acre unless supplemental aeration is provided.

Areas (exclosures) should be located at intervals along basin edges to provide clear zones for aeration and to enhance fish production for mosquito control. Total area for exclosures should be around 20 percent of the total hyacinth basin area. These exclosures should have a uniform depth of not more than 24 inches with the bottoms covered with broken rock or washed gravel.

Plastic sheeting covered with a layer of broken rock or washed gravel should extend above and below the operating level all along the inner basin berms to prevent weed growth and eliminate mosquito breeding habitat. Hyacinth basins must be kept weed-free at all times.

Mosquito control is very important for water hyacinth systems. The system should be designed so that the natural predators of mosquito larvae (mosquito fish, dragonflies, damsel fly nymphs, frogs, grass shrimp and a variety of water beetles) will thrive. Since most of these natural predators are strict aerobes, the system must be designed to prevent the occurrence of anaerobic conditions, especially in the vicinity of influent locations, where mosquito production is most likely to occur. To avoid anaerobic conditions the wastewater BOD load to the hyacinth system must be kept low and evenly distributed over the influent area.

Harvesting the plants for maintenance purposes requires 72 operator-days per year for one a MGD system. Plant harvest may be accomplished using a modified hydraulic hay rake mounted on a backhoe. The relatively small amount of plant material harvested may be composted, either alone or with wastewater sludge.

The major advantages of water hyacinth systems are the lack of mechanical equipment and low energy requirements. For these reasons, the use of aeration systems and greenhouses could reduce the cost effectiveness of these systems.

6.63 Acknowledgment

Major portion of this section was prepared on the basis of information provided by Mr. Ray Dinges, Consultant, Austin, Texas. His assistance and contributions in this are sincerely appreciated. The references listed under additional reading were also used.

6.64 Additional Reading

1. Hauser, J. R., "Use of water hyacinth aquatic treatment systems for ammonia control and effluent polishing," J. Water Pollution Control Federation, Volume 56, p. 219 (1984).
2. Weber, A. S., and Tchobanoglous, G., "Rational design parameters for ammonia conversion in water hyacinth treatment systems," J. Water Pollution Control Federation, Volume 55, p. 315 (1985).
3. Weber, A. S., and Tchobanoglous, G., "Prediction of nitrification in water hyacinth treatment systems," J. Water Pollution Control Federation, Volume 58, p. 376 (1986).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 390.

6.6A Why is proper venting important in a greenhouse containing a hyacinth culture?

6.6B Why is a fixed barrier installed at the outlet of a hyacinth basin?

DISCUSSION AND REVIEW QUESTIONS

Chapter 6 NITROGEN REMOVAL

Please write your answers in your notebook before working the Objective Test on page 391. The purpose of these questions is to indicate to you how well you understand the material in this chapter.

1. Why are algal growths undesirable in receiving waters?
2. List the limitations of the various modes of the activated sludge process in the nitrification process.
3. How can an operator use the results of the ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) tests to control the nitrification process?
4. Why do attached growth reactors use recirculation?
5. Why must the carbon feed source be carefully controlled in an attached growth reactor?
6. How does air come in contact with the wastewater in the air stripping process?
7. Why is calcium carbonate scale a problem in the air stripping process?
8. Why is secondary effluent or filtered effluent the appropriate application for breakpoint chlorination?
9. How does a hyacinth culture remove nitrogen and phosphorus from the wastewater being treated?
10. Why have recirculation, upwelling, and aeration not been successful in improving the performance of hyacinth cultures?

SUGGESTED ANSWERS

Chapter 6 NITROGEN REMOVAL

Answers to questions on page 373.

6.0A The two main nutrients which cause algal growths in receiving waters are nitrogen and phosphorus.

6.1A Nitrogen is removed by the nitrification/denitrification process. First bacteria convert the ammonium ion to the nitrite ion and the nitrite ion to the nitrate ion. Then in the denitrification process, bacteria convert the nitrate ion to nitrogen gas and gaseous nitrous oxide, both of which can be removed from the wastewater being treated as a gas.

6.1B The recommended use of breakpoint chlorination is to polish treatment plant effluent by decreasing the small amounts of remaining ammonia nitrogen.

6.1C Ammonium nitrogen is removed by the ion exchange process when the ammonium ion is exchanged with another ion on the ion exchange media (resin).

6.2A Nitrification can be accomplished using suspended growth reactors or attached growth reactors.

Answers to questions on page 377.

6.2B Alkalinity can be sustained in a nitrification process by adding calcium oxide (lime) or soda ash.

6.2C Nitrogen tests that must be performed at various key points along the reactors during the nitrification process include ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-).

6.2D Oxygen is provided in attached growth nitrification processes by natural or forced ventilation. Blowers or fans can provide the forced ventilation from the bottom to the top of the reactor.

6.2E The wastewater flow distributed over the surface of a nitrification tower must be at an optimum rate because excessive flow may cause a sloughing or washing off of the film with the valuable zoogleal growth that provides for the desired nitrification. If flow is insufficient the death of organisms due to drying out, insufficient oxygen or lack of food may result in an incomplete nitrification reaction.

6.2F A constant wastewater flow and the appropriate oxygen levels must be monitored closely when operating attached growth nitrification processes. Other factors requiring monitoring include influent BOD (should be low) and ammonia and also proper recirculation or recycle rates.

Answers to questions on page 382.

6.3A Denitrification relies on an environment for the wastewater and bacteria which is void of free oxygen. The bacteria must be forced to acquire the necessary oxygen for cell metabolism from the nitrate ion.

6.3B In a fluidized bed reactor, sand is the fixed film on which organisms can attach.

6.3C The two kinds of denitrification reactors are (1) attached growth reactors (fluidized bed reaction vessel) and (2) suspended growth reactor (aeration basin operated without oxygen or air being introduced).

6.3D If free oxygen is present in the denitrification process, there will be a reduction in the process efficiency.

Answers to questions on page 385.

6.4A The environmental conditions important for a successful ammonia stripping process are wastewater pH, temperature and air movement.

6.4B Two operating problems of the air stripping process are (1) calcium carbonate scale and (2) freezing.

6.4C Calcium carbonate scale is formed during the air stripping process when the carbon dioxide in the atmosphere combines with calcium oxide (used to increase the pH) and produces limestone (calcium carbonate scale).

6.4D Calcium carbonate scale can be removed with acid or hot water on a routine basis to maintain pumps, piping and other stripping equipment, including media packing.

Answers to questions on page 387.

6.5A By adding sufficient quantities of chlorine to wastewater containing ammonia nitrogen, the complete oxidation of the ammonia nitrogen takes place at a level of chlorine addition normally referred to as the "breakpoint."

6.5B Secondary or filtered effluent is the appropriate application for breakpoint chlorination. Breakpoint chlorination also is frequently used as final clean up following other nitrogen removal processes.

Answers to questions on page 389.

6.6A Proper venting is important in a greenhouse containing a hyacinth culture to expel excess heat in the summer and to retain heat in the winter.

6.6B A fixed barrier is installed at the outlet of a hyacinth basin to retain hyacinth and to create a clear water zone.

OBJECTIVE TEST

Chapter 6 NITROGEN REMOVAL

Please mark the correct answers on an answer sheets as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

1. The most common types of nitrogen removal systems include
   1. Ammonia stripping.
   2. Breakpoint chlorination.
   3. Denitrification.
   4. Filtration.
   5. Precipitation and sedimentation.
2. Important items for the successful operation of a suspended growth reactor (aeration basin) include appropriate
   1. Chlorine residual.
   2. Influent wastewater.
   3. Oxygen.
   4. Suspended solids.
   5. Time for aeration.
3. Proper operation of a fixed attached growth (fixed film) reactor requires adequate
   1. Detention time.
   2. Mixed liquor.
   3. Oxygen.
   4. Size of reactor.
   5. Suspended solids.
4. Which one of the following activated sludge process modes is best suited for nitrification?
   1. Complete mix
   2. Contact stabilization
   3. Conventional or plug flow
   4. Modified aeration
   5. Step-feed aeration
5. Too low dissolved oxygen levels in the effluent from a nitrification tower will result in
   1. Death of microorganisms.
   2. Lack of nitrogen conversion by bacterial growths.
   3. Plugged diffusers.
   4. Reduced process efficiency.
   5. Unbalanced distributor arms.
6. Which of the following can be used as a food source in an attached growth (fixed film) reactor?
   1. High carbon food
   2. Methane gas
   3. Methanol
   4. Primary effluent
   5. Secondary effluent
7. The pH of wastewater can be increased for air stripping by the addition of
   1. Carbon dioxide.
   2. Calcium oxide.
   3. Lime.
   4. Methanol.
   5. Sulfuric acid.
8. Careful control of chlorine feed in the removal of nitrogen in the breakpoint chlorination process is important because improper feed will result in
   1. Ammonia nitrogen not being properly removed.
   2. Effluent coliform standards not being met.
   3. Excess chlorine in the effluent being hazardous to aquatic life.
   4. Filamentous organisms preventing proper effluent clarification.
   5. Tastes and odors developing in downstream water supplies.
9. Hyacinth cultures have been used to remove ________ from wastewaters.
   1. BOD
   2. Coliform
   3. Nitrogen and phosphorus
   4. Toxic chemicals
   5. TDS
10. The major advantages of water hyacinth systems include
    1. Ability to withstand extreme temperature fluctuations.
    2. Economic returns from harvested hyacinth.
    3. Lack of mechanical equipment.
    4. Low energy requirements.
    5. Low quality effluent.
11. Flows through hyacinth basins are uniformly distributed by the use of
    1. Baffles.
    2. Orifice plates.
    3. Perforated pipe.
    4. Pumps.
    5. Weirs.
12. Mosquitoes can be controlled in hyacinth basins by
    1. Evapotranspiration.
    2. Grass shrimp.
    3. Minnows.
    4. Moths.
    5. Removing weeds.

End of Objective Test

CHAPTER 7

WASTEWATER RECLAMATION

by

Daniel J. Hinrichs

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OBJECTIVES

Chapter 7. WASTEWATER RECLAMATION

Following completion of Chapter 7, you should be able to do the following:

1. Safely operate and maintain a wastewater reclamation facility,
2. Describe the various methods of wastewater reclamation,
3. Develop operational strategies for wastewater reclamation facilities,
4. Monitor a wastewater reclamation program and make appropriate adjustments in treatment processes, and
5. Review the plans and specifications for a wastewater reclamation facility.

GLOSSARY

Chapter 7. WASTEWATER RECLAMATION

CATION EXCHANGE CAPACITY CATION EXCHANGE CAPACITY

The ability of a soil or other solid to exchange cations (positive ions such as calcium, Ca^{+2}) with a liquid.

DRAINAGE WELLS DRAINAGE WELLS

Wells that can be pumped to lower the ground water table and prevent ponding.

DRAIN TILE SYSTEMS DRAIN TILE SYSTEMS

A system of tile pipes buried under the crops that collect percolated waters and keep the groundwater table below the ground surface to prevent ponding.

EVAPOTRANSPIRATION (e-VAP-o-tran-spi-RAY-shun) EVAPOTRANSPIRATION

The total water removed from an area by transpiration (plants) and by evaporation from soil, snow and water surfaces.

HYDROLOGIC CYCLE (HI-dro-loj-ic) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement and runoff into rivers, streams and the ocean.

RECHARGE RATE RECHARGE RATE

Rate at which water is added beneath the surface of the ground to replenish or recharge groundwater.

RECLAMATION RECLAMATION

The operation or process of changing the condition or characteristics of water so that improved uses can be achieved.

RECYCLE RECYCLE

The use of water or wastewater within (internally) a facility before it is discharged to a treatment system. Also see REUSE.

REUSE REUSE

The use of water or wastewater after it has been discharged and then withdrawn by another user. Also see RECYCLE.

SIDESTREAM SIDESTREAM

Wastewater flows that develop from other storage or treatment facilities. This wastewater may or may not need additional treatment.

SODIUM ADSORPTION RATIO (SAR) SODIUM ADSORPTION RATIO

This ratio expresses the relative activity of sodium ions in the exchange reactions with soil. The ratio is defined as follows:

$$\text{SAR} = \frac{\text{Na}}{[\frac{1}{2}(\text{Ca} + \text{Mg})]^{\frac{1}{2}}}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water.

$$\text{Na, meq}/L = \frac{\text{Na, mg}/L}{23.0 \text{ mg/meq}} \qquad \text{Ca, meq}/L = \frac{\text{Ca, mg}/L}{20.0 \text{ mg/meq}}$$

$$\text{Mg, meq}/L = \frac{\text{Mg, mg}/L}{12.15 \text{ mg/meq}}$$

CHAPTER 7. WASTEWATER RECLAMATION

(Lesson 1 of 2 Lessons)

DIRECT REUSE OF EFFLUENT

7.0 USES OF RECLAIMED WASTEWATER

7.00 Direct Reuse of Effluent

Why might the effluent from your wastewater treatment plant be reused directly by someone? The main reason is that someone needs water and the effluent from your wastewater treatment plant is of an acceptable quality to meet their needs. Effluent reuse is considered when (1) the volume of municipal water needed is not available, (2) the cost of purchasing available treated water is too expensive, (3) surface waters are not available or the cost of treatment is excessive, and (4) groundwaters are either not available or the costs of pumping and any treatment is prohibitive. In the future as discharge requirements become more and more stringent, the quality of plant effluents will become more and more attractive as the best available source of water. For these reasons, you must be able to produce an effluent that can be used either directly or reclaimed for beneficial uses. Effluent from wastewater may be reclaimed for the uses listed in Table 7.1. Table 7.2 lists the treatment levels necessary for various beneficial uses.

Irrigation is covered in Lesson 2, "Effluent Disposal on Land." Indirect reuse is the same as disposal by dilution. Groundwater recharge by spreading basins is included with the section on irrigation. This section includes direct reuse by industry, deep well injection, and recreation (Figures 7.1, 7.2 and 7.3). Generally, the operation of these systems is similar.

If water or wastewater is used again within (internally) a facility before it is discharged to a treatment system, this water is considered *RECYCLED.* If this water is discharged and then withdrawn by another user, the water is *REUSED. RECLAMATION* is the operation or process of changing the condition or characteristics of water so that improved uses can be achieved.

TABLE 7.1 TREATMENT LEVELS REQUIRED FOR VARIOUS BENEFICIAL USES[a]

Beneficial Use	Treatment Levels[b]
Agricultural Irrigation — Forage Crops	1
Agricultural Irrigation — Truck Crops	1
Urban Irrigation — Landscape	4
Livestock and Wildlife Watering	1
Power Plant and Industrial Cooling	
Once-through	1
Recirculation	1
Industrial Boiler Make-up	
Low pressure	6
Intermediate pressure	10
Industrial Water Supply	
Petroleum and Coal Products	3a or 4
Primary Metals	1
Paper and Allied Products	5c or 8
Chemicals and Allied Products	7 to 11
Food Products	7 to 11
Fisheries	
Warm Water	6
Cold Water	6
Recreation	
Secondary Contact	4
Primary Contact	5 or 6
Public Water Supply	
Groundwater, spreading	13b
Groundwater, injection	11
Surface Water	9, 10, or 12
Direct Potable	11

[a] *WATER REUSE AND RECYCLING*, Volume 2, *EVALUATION OF TREATMENT TECHNOLOGY*, by Culp/Wesner/Culp for Department of Interior, Office of Water Research and Technology, OWRT/RU-7911, Washington, D.C. 1979.

[b] See Table 7.2 for an explanation of processes that produce the desired treatment levels.

TABLE 7.2 TREATMENT LEVELS[a]

Treatment Level	Treatment System
1a	Activated sludge
1b	Trickling filter
1c	Rotating biological contactors
2a	2-Stage nitrification
2b	Rotating biological contactors
2c	Extended aeration
3a	Nitrification-Denitrification
3b	Selective ion exchange
4	Filtration of secondary effluent
5a	Alum added to aeration basin
5b	Ferric chloride added to primary
5c	Tertiary lime treatment
6a	Tertiary lime, nitrified effluent
6b	Tertiary lime plus ion exchange
7	Carbon adsorption, filtered secondary effluent
8	Carbon, tertiary lime effluent
9	Carbon, tertiary lime, nitrified effluent
10	Carbon, tertiary lime, ion exchange
11	Reverse osmosis of AWT effluent
12a	Physical-Chemical system, lime
12b	Physical-Chemical system, ferric chloride
13a	Irrigation
13b	Infiltration-Percolation
13c	Overland flow

[a] *WATER REUSE AND RECYCLING*, Volume 2, *EVALUATION OF TREATMENT TECHNOLOGY*, by Culp/Wesner/Culp for Department of Interior, Office of Water Research and Technology, OWRT/RU-7911, Washington, D.C. 1979.

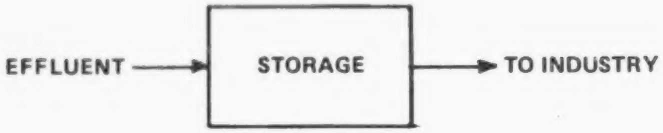

EFFLUENT
STORAGE
TO INDUSTRY

Fig. 7.1 Industrial reuse

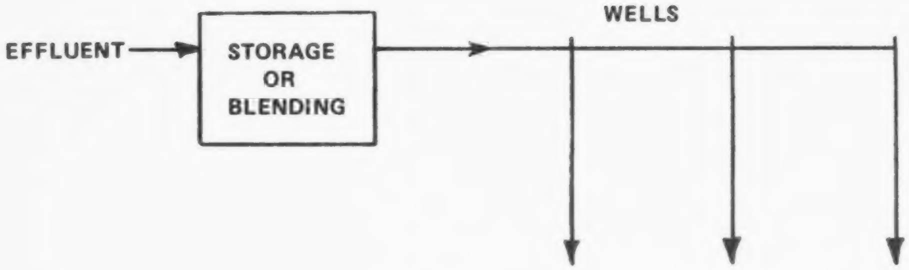

EFFLUENT
STORAGE OR BLENDING
WELLS

Fig. 7.2 Deep well injection

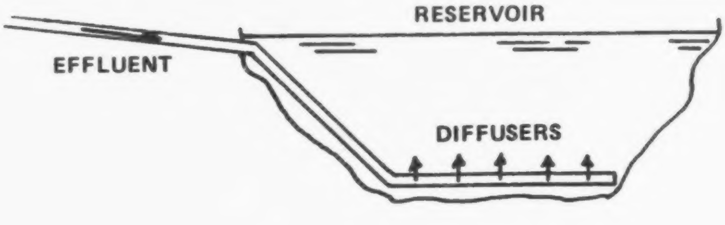

RESERVOIR
EFFLUENT
DIFFUSERS

Fig. 7.3 Recreation use

7.01 Equipment Requirements

Equipment used in wastewater reclamation plants is very similar to equipment used in most conventional wastewater treatment plants. Equipment requirements consist of a transmission system of pipes, ditches, or canals to transport water to the user's location. Metering and control systems are necessary for monitoring flows and water quality delivered to users.

Deep well injection systems include pipelines, pumps, and wells along with the meters and control equipment. Often, treated effluent (the reclaimed wastewater) is mixed with fresh water prior to injection to dilute the treated effluent. In these instances a blending tank is required. Effluent and fresh water are pumped to the blending tank and the mixture is pumped to the injection wells. Most injection systems are used in coastal areas to serve as barriers for preventing contamination of groundwater by salt water. There may be other uses for injection wells such as injection into oil wells to aid oil pumping operations. Oil that was not removed by previous pumping efforts will float on top of water and be easier to pump from underground areas.

The equipment requirements for disposal to a recreation lake are basically the same as disposal by dilution (Chapter 13, Volume II).

There are several variations possible with these systems, but each must provide a means for delivering water to the point of use. In some instances storage or blending with fresh water may be desired, so Figures 7.1 and 7.2 show provisions for storage.

7.02 Limitations of Direct Reuse

Industrial reuse of wastewater will increase in the future. Water quality requirements for industrial use vary considerably. For example, cooling and washing waters do not require as high or as consistent a quality as water used in food processing or manufacturing processes. For these reasons large industries often have their own water treatment plants on the site to provide the degree of treatment required for production processes. Under these conditions reclaimed effluent may be used directly for washing purposes or serve as influent to a specialized water treatment plant. In either case, industries desire as consistent a quality as possible from your wastewater reclamation plant.

Regardless of the use of treated effluent or reclaimed wastewater, the user of the water will expect the water to be supplied to meet specific water quality criteria. These criteria are just as important as NPDES permit requirements. If water quality criteria are not met, operators must have a plan to notify users, or to store or to dispose of the inadequately treated wastewater.

Industrial reuse requires a fairly uniform quality of water. If any water quality indicator fluctuates, notify the industrial user. Water quality indicators of concern include but are not limited to temperature, pH, color, and hardness or scale-forming minerals such as calcium, magnesium and iron.

Deep well injection must follow procedures developed to maintain the *RECHARGE RATES.*[1] Important considerations include type of pumps, pump discharge pressures and maintenance of any venting systems. Slime growths caused by organisms in the presence of proper temperature, food and nutrients can reduce recharge rates. Care must be taken to avoid contamination of groundwaters used as a drinking water supply. Groundwaters can be contaminated by the discharge of excessive amounts of trace organics, minerals, nutrients or toxic materials.

Water reclaimed for recreation use must consider protection of public health and aesthetics. As a minimum standard, public health considerations require the absence of pathogens as measured by the coliform group bacteria test. Aesthetics are evaluated by the lack of floatables and scums. The clearer a body of water, the more pleasing the appearance. Nutrients can contribute to algal growths which reduce the aesthetic value of water used for recreation. Inadequate removal of BOD can result in the depletion of oxygen in the receiving waters which may cause fish kills.

Table 7.1 lists the various beneficial uses of water that are quite likely to use reclaimed water now and in the future. These different uses require different treatment processes and degrees of treatment (treatment levels) to produce a reclaimed effluent suitable for direct reuse by industry or other type of water user. These treatment levels are described in terms of treatment processes or treatment systems in Table 7.2. To determine the effluent quality you should expect from a wastewater reclamation plant, Table 7.3 lists the expected effluent quality from various combinations of treatment processes used to reclaim wastewater. This table also could be used to determine whether the effluent could be used by certain beneficial uses.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 429.

7.0A List the possible uses of reclaimed wastewater.

7.0B How can deep well injection aid oil pumping operations?

7.03 Case Histories

The following case histories were developed at actual operating wastewater reclamation facilities. The data shown for the first three case histories were taken from *HEALTH ASPECTS OF WASTEWATER RECHARGE.* This publication was prepared by a consulting panel for the California State Water Resources Control Board, Department of Water Resources and Department of Health.

7.030 South Lake Tahoe Public Utility District, California (Fig. 7.4)

This system was developed to treat wastewater for reuse in a recreation lake and for crop irrigation. The unit processes include primary sedimentation, activated sludge, lime addition and chemical clarification, ammonia stripping, filtration, activated carbon adsorption, and chlorination. The major function of the primary sedimentation process is to remove suspended solids. The activated sludge process removes suspended solids and BOD. Lime addition and chemical clarification remove phosphorus. Ammonia removal is accomplished by ammonia stripping towers. Filters are provided for suspended solids and turbidity removal. The activated carbon adsorption process removes COD, BOD, and methylene blue active substances (MBAS, a surface active agent). The chlorination process is provided for pathogen reduction and during cold weather is used for nitrogen removal by breakpoint chlorination.

---

[1] *Recharge Rate. Rate at which water is added beneath the surface of the ground to replenish or recharge groundwater.*

TABLE 7.3 ANTICIPATED PERFORMANCE OF VARIOUS UNIT PROCESS COMBINATIONS[a]

		ESTIMATED AWT PROCESS EFFLUENT QUALITY						
AWT Pretreatment	**AWT Process[b]**	**BOD (mg/L)**	**COD (mg/L)**	**Turb. (JU)**	**PO_4 (mg/L)**	**SS (mg/L)**	**Color (units)**	**NH_3–N (mg/L)**
Preliminary[c]	C,S	50-100	80-180	5-20	2-4	10-30	30-60	20-30
	C,S,F	30-70	50-150	1-2	0.5-2	2-4	30-60	20-30
	C,S,F,AC	5-10	25-45	1-2	0.5-2	2-4	5-20	20-30
	C,S,NS,F,AC	5-10	25-45	1-2	0.5-2	2-4	5-20	1-10
Primary	C,S	50-100	80-180	5-15	2-4	10-25	30-60	20-30
	C,S,F	30-70	50-150	1-2	0.5-2	2-4	30-60	20-30
	C,S,F,AC	5-10	25-45	1-2	0.5-2	2-4	5-20	20-30
	C,S,NS,F,AC	5-10	25-45	1-2	0.5-2	2-4	5-20	1-10
High-rate Trickling Filter	F	10-20	35-60	6-15	20-30	10-20	30-45	20-30
	C,S	10-15	35-55	2-9	1-3	4-12	25-40	20-30
	C,S,F	7-12	30-50	0.1-1	0.1-1	0-1	25-40	20-30
	C,S,F,AC	1-2	10-25	0.1-1	0.1-1	0-1	0-15	20-30
	C,S,NS,F,AC	1-2	10-25	0.1-1	0.1-1	0-1	0-15	1-10
Conventional Activated Sludge	F	3-7	30-50	2-8	20-30	3-12	25-50	20-30
	C,S	3-7	30-50	2-7	1-3	3-10	20-40	20-30
	C,S,F	1-2	25-45	0.1-1	0.1-1	0-1	20-40	20-30
	C,S,F,AC	0-1	5-15	0.1-1	0.1-1	0-1	0-15	20-30
	C,S,NS,F,AC	0-1	5-15	0.1-1	0.1-1	0-1	0-15	1-10

[a] From *HANDBOOK OF ADVANCED WASTEWATER TREATMENT,* Second Edition, by Russell L. Culp, George M. Wesner and Gordon L. Culp. Copyright 1978 by Litton Educational Publishing, Inc. Reprinted by permission of Van Nostrand Reinhold.

[b] C,S - Coagulation and sedimentation; F - mixed-media filtration; AC - activated carbon adsorption; NS - ammonia stripping. Lower effluent NH_3 value at 18°C.[d]

[c] Preliminary treatment - grit removal, screen chamber, Parshall flume, overflow.

[d] For details on C, S and F, see Chapter 4; NS, Chapters 2 and 6 for ammonia removal by nitrification; and AC, Chapter 6, in *INDUSTRIAL WASTE TREATMENT.*

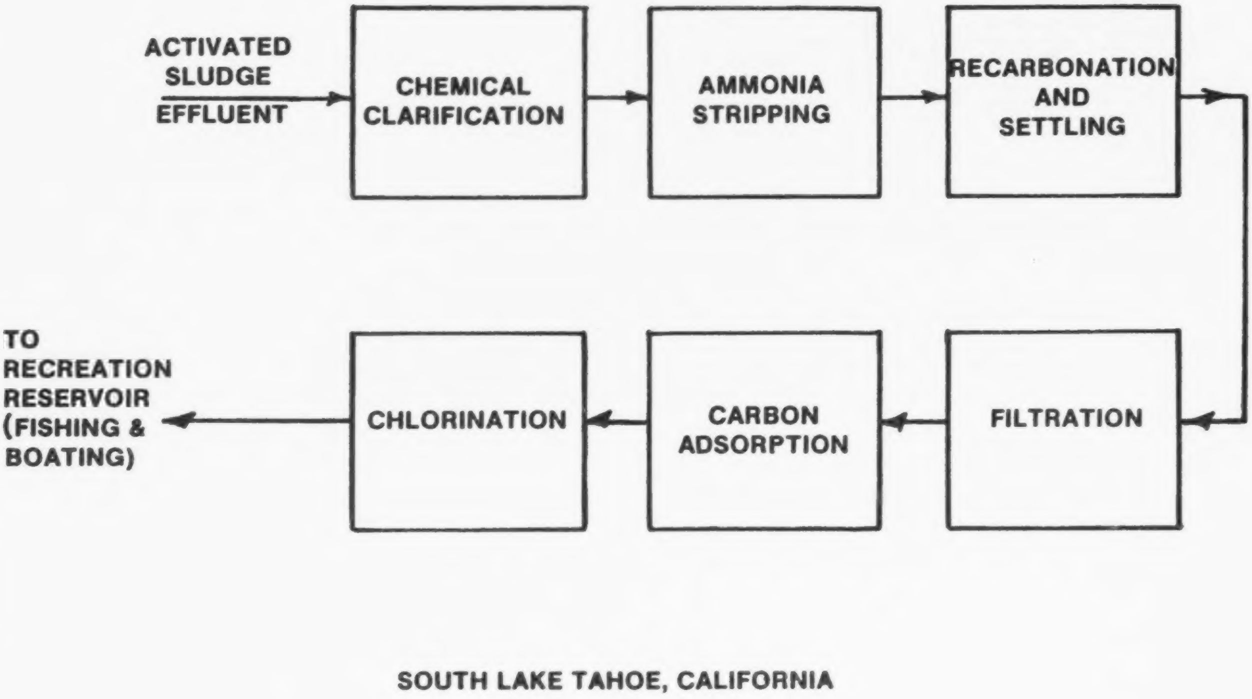

ACTIVATED SLUDGE EFFLUENT
CHEMICAL CLARIFICATION
AMMONIA STRIPPING
RECARBONATION AND SETTLING
FILTRATION
CARBON ADSORPTION
CHLORINATION
TO RECREATION RESERVOIR (FISHING & BOATING)
SOUTH LAKE TAHOE, CALIFORNIA

Fig. 7.4 Wastewater reclamation processes used at South Lake Tahoe, California

These processes remove BOD, COD, suspended solids, turbidity, nitrogen, phosphorus, and pathogens from the water being treated. These constituents are removed to make the recreation lake safe for human contact (pathogen removal), prevent unsightly algae growth (nitrogen and phosphorus removal), and provide a pleasant appearance (suspended solids and turbidity removal). Table 7.4 shows water quality following each of these unit processes.

7.031 Muskegon County, Michigan (Fig. 7.5)

This system reclaims wastewater for crop irrigation. Irrigation water leaches through the soil and then enters two streams through the subsurface drainage system. The treatment process consists of aerated ponds and during cold weather, storage lagoons. These processes reduce BOD, suspended solids, and pathogens. The purpose of this treatment system is primarily to prevent nuisance conditions from developing in the fields. The soil provides additional treatment to water passing through the soils to the drain tiles. Table 7.5 shows water quality indicators at various stages in the process.

7.032 Windhoek, South Africa (Fig. 7.6)

Wastewater is treated in ponds and then reclaimed and blended with other water for a drinking water supply. The processes consist of recarbonation of pond effluent followed by algae flotation, chemical clarification, breakpoint chlorination, filtration, and carbon adsorption. Recarbonation lowers the pH. Algae flotation removes algae to prevent taste and odor problems. Chemical clarification removes phosphorus and turbidity. Breakpoint chlorination destroys pathogens and reduces ammonia levels. Suspended solids and COD are removed by filtration and carbon adsorption. Treatment results are shown on Table 7.6.

7.033 Nuclear Generating Station, Phoenix, Arizona (Fig. 7.7)

Secondary effluent from the City of Phoenix's Wastewater Treatment Plant is pumped 40 miles (64 km) through a pipeline to the Arizona Public Service's Palo Verde Nuclear Generating Station in the desert. Advanced waste treatment processes produce a highly treated water that is used for make-up water in the cooling towers. There are no liquid discharges from the process and the reclamation plant meets the requirement of "no discharge."

The function of the Water Reclamation Facility is to supply suitable feedwaters for all of the Palo Verde Nuclear Generating Station site uses. The largest water use by far will be the circulating water cooling tower makeup of up to 60,000 GPM (327,000 cu m/day) for all three units. This flow rate is based on 15 cycles of concentration in the cooling towers. Since some of the constituents in this water will cause problems of corrosion or deposition, the water is chemically treated before use (Table 7.7). Ammonia causes corrosion of copper and contributes to biological growths in the storage reservoir. Alkalinity contributes to scale formation. Biochemical oxygen demand (BOD) is a measure of the organic materials in the water and contributes to organic materials that cause fouling in condenser tubes. Calcium and magnesium contribute to scale formation as do silica and sulfate. Phosphorus also accelerates biological growth in the storage reservoir. Suspended solids cause sludge formation or deposits.

TABLE 7.5 MUSKEGON TREATMENT RESULTS

Water Quality Indicator	Plant Influent	Aerated Ponds	Lagoon	Drain Tiles	Creeks
BOD, mg/*L*	220	85	12.5	2.2	2
DO, mg/*L*	0	1.5	6	2.9	1.6
Suspended Solids, mg/*L*	325	250	15	0	20
Ammonia, mg/*L*	9	5	1.4	0.4	0.5
Nitrate, mg/*L*	0	.06	1.6	2.8	1.6
Phosphate, mg/*L*	6.5	5	2.9	.05	.08

Upon arrival at the nuclear power site the first treatment process is biological nitrification (Fig. 7.7) by the use of trickling filters with plastic media. Nitrificaiton is used to convert the ammonia to nitrate. An additional advantage of this process is a reduction in alkalinity with a subsequent 50 percent reduction in lime demand and sludge handling. Fifty percent of the water going through the nitrification process is recycled to stabilize the results.

Lime ($Ca(OH)_2$) is added to the effluent from the trickling filters to increase the pH to 11.3. Lime addition is used to precipitate solids and also to reduce the magnesium (90%) and silica (75%) content in order to control scaling problems. Lime reduces the phosphate content by 95 percent. Sodium carbonate (Na_2CO_3) is added to precipitate calcium and soften the water. After lime and sodium carbonate are added and mixed with the water, solids-contact clarifiers (Fig. 7.8) are used to allow the solids and precipitates to settle out.

TABLE 7.4 LEVELS OF WATER QUALITY INDICATORS AFTER EACH UNIT PROCESS

	UNIT PROCESSES							
Water Quality Indicator	Raw Wastewater	Primary	Secondary	Chemical Clarification	Ammonia Stripping	Filtration	Carbon Adsorption	Chlorination
BOD (mg/*L*)	140	100	30	30	30	3	1	0.7
COD (mg/*L*)	280	220	70	70	70	25	10	10
SS (mg/*L*)	230	100	26	10	10	0	0	0
Turbidity (JTU)	250	150	15	10	10	0.3	0.3	0.3
MBAS (mg/*L*)	7	6	2	2	2	0.5	0.1	0.1
Ammonia (mg/*L*)	20	20	15	15	1	1	1	1
Phosphorus mg/*L*)	12	9	6	0.7	0.7	0.1	0.1	0.1
Coliform MPN/100 ml	50	15	25	50	50	50	50	<2.2

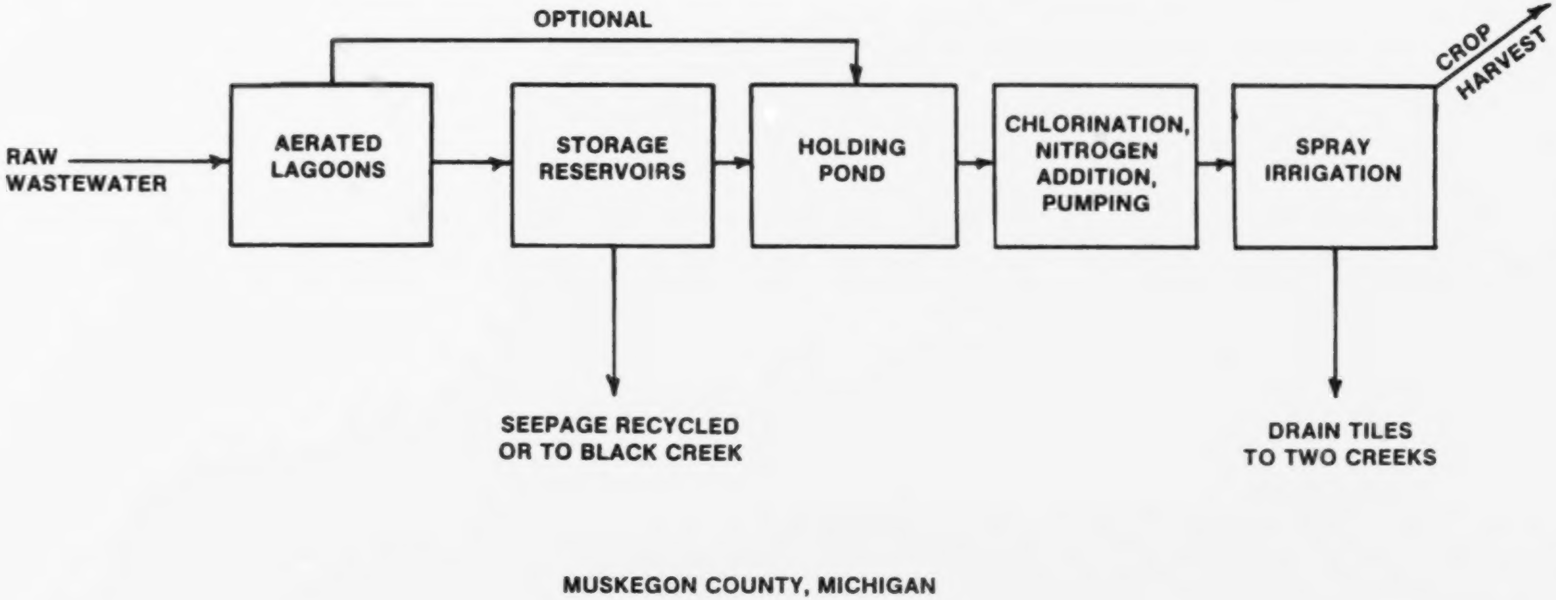
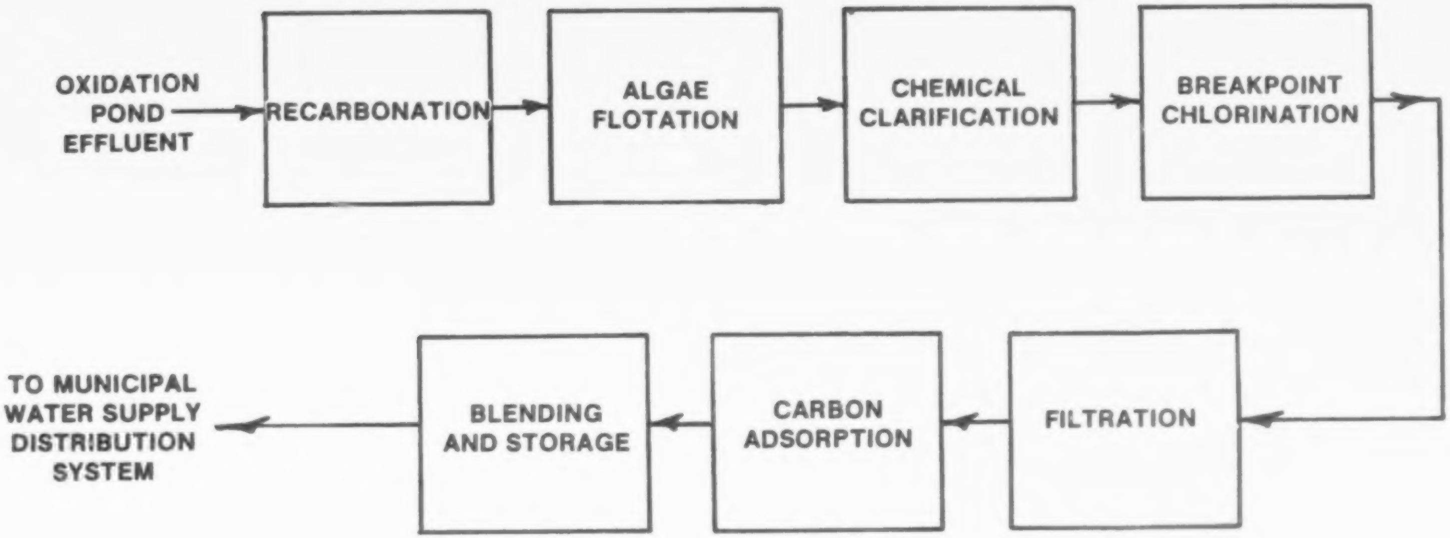

OPTIONAL
RAW WASTEWATER
AERATED LAGOONS
STORAGE RESERVOIRS
HOLDING POND
CHLORINATION, NITROGEN ADDITION, PUMPING
SPRAY IRRIGATION
CROP HARVEST
SEEPAGE RECYCLED OR TO BLACK CREEK
DRAIN TILES TO TWO CREEKS
MUSKEGON COUNTY, MICHIGAN

Fig. 7.5 Wastewater reclamation processes used at Muskegon County, Michigan


OXIDATION POND EFFLUENT
RECARBONATION
ALGAE FLOTATION
CHEMICAL CLARIFICATION
BREAKPOINT CHLORINATION
FILTRATION
CARBON ADSORPTION
BLENDING AND STORAGE
TO MUNICIPAL WATER SUPPLY DISTRIBUTION SYSTEM

WINDHOEK, SOUTH AFRICA

Fig. 7.6 Wastewater reclamation processes used at Windhoek, South Africa

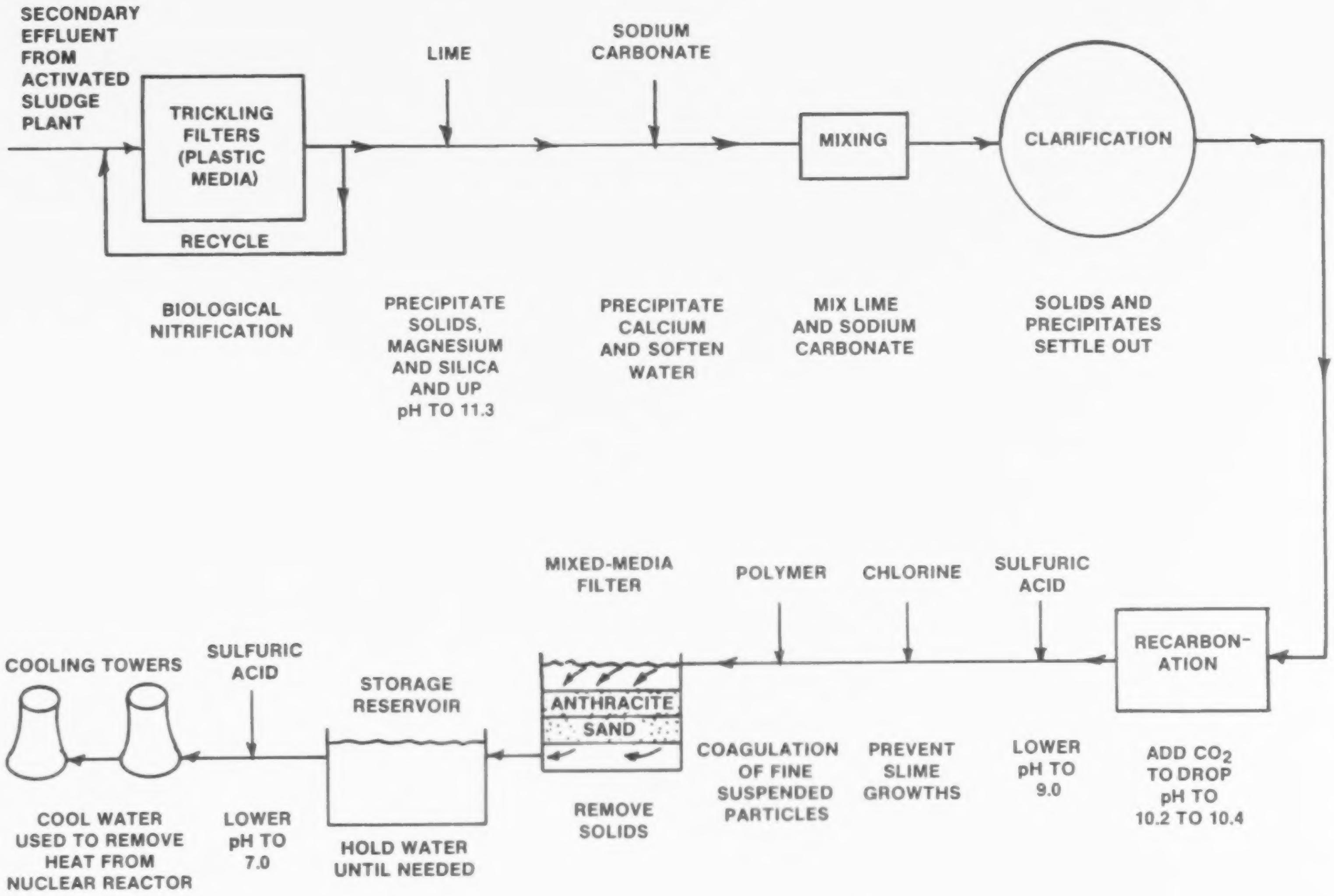

SECONDARY EFFLUENT FROM ACTIVATED SLUDGE PLANT
TRICKLING FILTERS (PLASTIC MEDIA)
RECYCLE
LIME
SODIUM CARBONATE
MIXING
CLARIFICATION
BIOLOGICAL NITRIFICATION
PRECIPITATE SOLIDS, MAGNESIUM AND SILICA AND UP pH TO 11.3
PRECIPITATE CALCIUM AND SOFTEN WATER
MIX LIME AND SODIUM CARBONATE
SOLIDS AND PRECIPITATES SETTLE OUT
MIXED-MEDIA FILTER
POLYMER
CHLORINE
SULFURIC ACID
RECARBON-ATION
ANTHRACITE
SAND
COOLING TOWERS
SULFURIC ACID
STORAGE RESERVOIR
COAGULATION OF FINE SUSPENDED PARTICLES
PREVENT SLIME GROWTHS
LOWER pH TO 9.0
ADD CO2 TO DROP pH TO 10.2 TO 10.4
COOL WATER USED TO REMOVE HEAT FROM NUCLEAR REACTOR
LOWER pH TO 7.0
HOLD WATER UNTIL NEEDED
REMOVE SOLIDS

Fig. 7.7 Wastewater reclamation processes used for cooling towers at a nuclear generating station

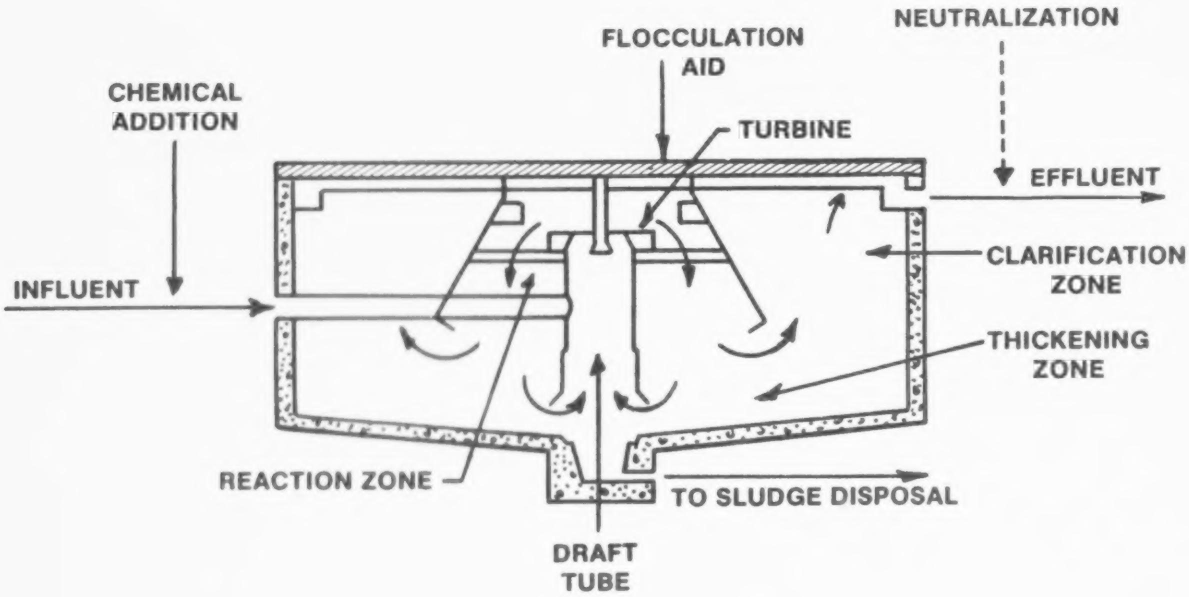

NEUTRALIZATION
FLOCCULATION AID
CHEMICAL ADDITION
TURBINE
EFFLUENT
CLARIFICATION ZONE
INFLUENT
THICKENING ZONE
REACTION ZONE
TO SLUDGE DISPOSAL
DRAFT TUBE

Fig. 7.8 Typical solids-contact clarifier

TABLE 7.6 TREATMENT RESULTS

Water Quality Indicator	Effluent	Flotation	Chemical Clarification and Chlorination	Filtration	Activated Carbon
Total N, mg/*L*	35	32	15	14	13
Organic N, mg/*L*	3.2	1.3	0.9	0.7	—
Ammonia N, mg/*L*	14.9	14	0.2	0.3	0.1
Nitrate, mg/*L*	17	17	14	13	13
Phosphate, mg/*L*	10	—	—	—	—
ABS,[a] mg/*L*	8	7	4	4	0.7
BOD, mg/*L*	30	4	1	1	0.3
pH	8.5	7.1	8.0	8.0	8.0

[a] **A**lkyl **B**enzene **S**ulfonate. A type of surfactant, or surface active agent, present in synthetic detergents in the United States before 1965. ABS was especially troublesome because it caused foaming and resisted breakdown by biological treatment processes. ABS has been replaced in detergents by **L**inear **A**lkyl **S**ulfonate (LAS) which is biodegradable.

TABLE 7.7 POTENTIAL PROBLEM CONSTITUENTS IN RECLAIMED WASTEWATER, mg/*L*

Constituent	Effluent From City Treatment Plant	Target for Reclaimed Water
Ammonia[a]	24 - 40	5
Alkalinity[b]	216 - 283	100
BOD	6 - 42	10
Calcium[b]	110 - 195	70
Magnesium[b]	60 - 116	8
Phosphorus[c]	14 - 41	0.5
Silica[d]	25 - 34	10
Sulfate	73 - 90	200
Suspended Solids	20 - 60	10

[a] mg/*L* as N
[b] mg/*L* as $CaCO_3$
[c] mg/*L* as P
[d] mg/*L* as SiO_2

After clarification carbon dioxide is used to lower the pH to between 10.2 and 10.4. Sulfuric acid is used to drop the pH to 9 and to stop the formation of any more calcium carbonate ($CaCO_3$). Chlorine is added to prevent slime growth in the filters, and polymer is used to facilitate coagulation of fine suspended particles. The water then passes through mixed-media gravity filters containing anthracite and sand to remove any fine or light solids remaining in suspension in the water. The filters are backwashed with water from the storage reservoir and the backwash water is recycled to the headworks of the trickling filters.

Effluent from the gravity filters is held in a reservoir until needed for cooling tower make-up water. When the water is pumped to the cooling towers the pH is lowered by the use of sulfuric acid to 7.0 to control scaling problems in the cooling towers.

Polymers are added to the solids from the clarifiers before treatment by a classification centrifuge to separate the calcium carbonate. Centrate (water from centrifuge) is recycled back to the trickling filter headworks. The calcium carbonate is passed through a multiple-hearth furnace to recover the lime for reuse. All residues not recycled from the centrifuge and ash from the furnace are disposed of in a landfill.

7.034 Specialty Steel Mill, Syracuse, New York (Fig. 7.9)

Wastewater reclamation and recycling at steel mills requires the identification of sources of wastewater and a determination of the best means of collecting, treating, and recycling or disposing of the wastewater. Table 7.8 summarizes sources of wastewater and treatment methods for a specialty steel mill.

TABLE 7.8 STEEL MILL WASTEWATER SOURCES AND TREATMENT

Source	Treatment
1. Cooling tower blowdown	Discharge into municipal collection system.
2. Rolling mill wastewaters	Collect, provide chemical treatment and recycle within mill.
3. Pickling rinse waters	Collect, provide chemical treatment and recycle within mill.
4. Spent pickling and plating baths	Haul to approved disposal site.
5. Sanitary wastewaters	Collect and discharge into municipal collection system.

Process wastewaters that receive chemical treatment are collected from the various sources in the mill and ultimately reach the aeration tank at the treatment plant (Fig. 7.9). Wastewater is aerated to convert soluble iron to an insoluble iron precipitate by oxidation and also to cool the water.

Chemicals are added in Tank A (similar to Fig. 7.8) to the effluent from the aeration tank. An anionic polymer and ferric chloride provide for chemical coagulation and flocculated solids are recycled within the clarifier (Tank A) in order to provide a prolonged contact between the entering wastewater and previously formed solids. This recycling process increases absorption of the pollutants into the floc particles. Clarified effluent flows over V-notch weirs and is reused in mill operations. The weirs are baffled to hold back floating materials. Water not recycled flows to Tank B (similar to Fig. 7.8) for additional treatment prior to discharge. Tables 7.9 and 7.10 show the removal efficiencies for Tanks (clarifiers) A and B.

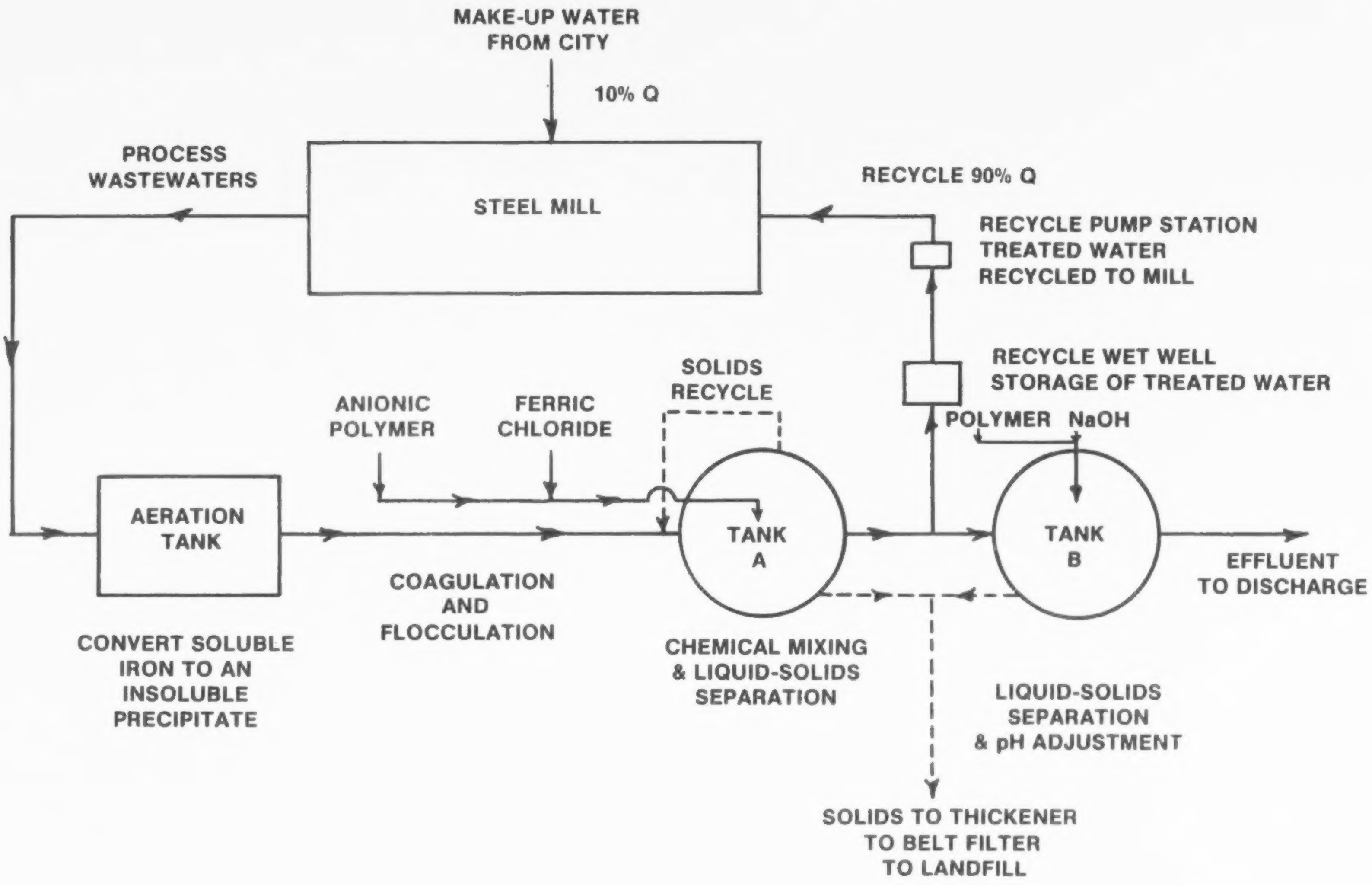

MAKE-UP WATER
FROM CITY
10% Q
PROCESS
WASTEWATERS
STEEL MILL
RECYCLE 90% Q
RECYCLE PUMP STATION
TREATED WATER
RECYCLED TO MILL
RECYCLE WET WELL
STORAGE OF TREATED WATER
SOLIDS
RECYCLE
ANIONIC
POLYMER
FERRIC
CHLORIDE
POLYMER
NaOH
AERATION
TANK
TANK
A
TANK
B
EFFLUENT
TO DISCHARGE
COAGULATION
AND
FLOCCULATION
CONVERT SOLUBLE
IRON TO AN
INSOLUBLE
PRECIPITATE
CHEMICAL MIXING
& LIQUID-SOLIDS
SEPARATION
LIQUID-SOLIDS
SEPARATION
& pH ADJUSTMENT
SOLIDS TO THICKENER
TO BELT FILTER
TO LANDFILL

Fig. 7.9 Wastewater reclamation processes for a specialty steel mill

Material contained in this section was obtained from a paper, "Optimization of Wastewater Treatment and Reuse at a Specialty Steel Mill," presented by Robert H. Wills, Jr., and Richard W. Klippel at the 52nd Annual Conference of the Water Pollution Control Federation Houston, Texas, October 7-12, 1979. Mr. Wills is Chief Operator of the Crucible Incorporated Wastewater Treatment and Reuse Facility, Syracuse, New York, and Mr. Klippel is Industrial Waste Manager for Calocerinos & Spina Consulting Engineers, Liverpool, New York. See Chapter 6, "Industrial Waste Treatment," Section 6.6, *INDUSTRIAL WASTE TREATMENT*, for details on how this wastewater reclamation facility is operated.

TABLE 7.9 REMOVAL EFFICIENCIES FOR TANK A, AVERAGE DAILY VALUES

Water Quality Indicator	Influent, mg/*L*	Effluent, mg/*L*	Removal, %
TSS	87.0	21.8	75
TOC	17.0	13.3	21
Cyanides-Total	0.06	0.49	18.4
Cyanides-Oxid.	.027	0.03	0
Nitrate	21.1	22.5	0
Sulfate	609.0	633.0	0
Chloride	106.0	113.0	0
Cadmium-Total	LT 0.01	LT 0.01	ND
Cadmium-Soluble	LT 0.01	LT 0.01	ND
Chromium-Hex.	0.15	0.02	86.7
Chromium-Total	3.80	0.75	80
Chromium-Soluble	0.83	0.14	83
Copper-Total	0.48	0.41	14.6
Copper-Soluble	0.10	0.35	0
Iron-Total	27.5	9.0	67.3
Iron-Soluble	4.2	1.95	53.5
Zinc-Total	0.64	0.56	12.5
Zinc-Soluble	0.32	0.51	0
Fluoride	13.9	16.8	0

LT means Less Than
ND means Not Determined

7.1 OPERATING PROCEDURES

Operating procedures are generally the same for each type of wastewater reclamation system with variations depending on the processes used. The procedures listed in this section apply mainly to the uses shown in Figures 7.1, 7.2 and 7.3.

7.10 Pre-start Inspection

1. Examine most recent lab test results.
2. Read preceding day's log for special instructions.

7.11 Start-up

1. Determine quantity of water required.
2. Read meter totalizer and log.
3. Open valves.
4. Open valves to blending tank from freshwater supply (if blending tank is used).
5. Start the pumps.

7.12 Normal Operation

1. Make one inspection per shift of each pump, check oil levels and packing, and clean area. Listen for any unusual sounds.
2. Lubricate equipment where necessary.
3. Record flow near the end of the shift.
4. Visually inspect product water every two hours. Look for unusual amounts of solids, floatables or colors, and try to detect any odors.
5. Collect samples and/or analyze samples immediately in accordance with Section 7.2, "Monitoring Program."

TABLE 7.10 REMOVAL EFFICIENCIES FOR TANK B, AVERAGE DAILY VALUES

Water Quality Indicator	mg/*L* Concentration			Kilograms Per 4-Hour Period		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal
TSS	21.8	9.0	58.6	4.45	1.99	55.3
TOC	13.3	9.8	26.3	2.72	1.95	28.3
Cyanides-Total	0.049	.062	0	0.016	0.02	0
Cyanides-Oxid.	0.03	.032	0	0.011	0.0059	46.3
Nitrate	22.5	21.8	3.2	4.54	5.9	0
Sulfate	633	654	0	129.3	127	1.8
Chloride	113	114	0	23	2.22	3.0
Cadmium-Total	ND	ND	0	ND	ND	0
Cadmium-Soluble	ND	ND	0	ND	ND	0
Chromium-Hex.	0.2	.022	0	0.0041	0.0045	70
Chromium-Total	0.75	.245	67.3	0.15	0.045	70
Chromium-Soluble	0.14	.03	79.6	0.03	0.006	80.0
Copper-Total	0.41	.063	84.6	0.08	0.012	85.0
Copper-Soluble	0.35	.017	95.1	0.07	0.002	97.1
Iron-Total	9.0	2.30	74.5	3.5	0.45	87.1
Iron-Soluble	1.95	.028	98.6	0.41	0.008	98.0
Zinc-Total	0.56	.13	76.8	0.113	0.027	76.0
Zinc-Soluble	0.51	.06	88.2	0.1	0.01	90
Fluoride	16.8	14.8	12.0	3.58	3.0	16.2

ND means Not Determined

7.13 Shutdown

1. Turn off pumps.
2. Close all valves.
3. Record meter totalizer reading.
4. Make entry in log.

7.14 Operational Strategy

System flows are controlled by pump run times and valve adjustments. If blending is used, then desired water quality constituent values are reached by adding fresh water. For example, if the plant effluent ammonia concentration is 20 mg/*L*, the desired concentration is 10 mg/*L*, and the fresh water ammonia concentration is zero, the delivered water should be slightly less than 50 percent plant effluent and slightly more than 50 percent fresh water.

The process control consists of techniques to blend flows or provide further treatment. Blending procedures are described in the previous paragraph. Further treatment can be accomplished by adding chemicals such as chlorine to kill coliform and pathogenic bacteria or aeration to increase dissolved oxygen. Unacceptable effluent could be returned to the treatment processes for further treatment.

Important observations include detection of odors and colors. Greases and oils also can be seen. Observations of any of these pollutants in the plant effluent means the treatment process is probably upset.

7.15 Emergency Operating Procedures

If one of the treatment processes fails and effluent quality standards cannot be met, immediately stop flow to the water users and send flow to emergency holding pond or tank, if one is available. Otherwise reroute the flow in accordance with established procedures to an acceptable means of disposal.

If the power is off, the flow must be contained in the emergency holding area.

7.16 Troubleshooting Guide (Table 7.11)

If your plant is not meeting the water quality requirements of the waters users, try to identify the cause of the problem and to select the proper corrective action. Solutions to the problems listed in this section have been covered in more detail in previous chapters.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 429.

7.1A How can coliform and pathogenic bacteria be killed in reclaimed wastewater?

7.1B Why is a "blend" water sometimes mixed with plant effluent?

7.1C What could be the probable causes of a wastewater reclamation plant being unable to maintain a chlorine residual?

7.2 MONITORING PROGRAM

7.20 Monitoring Schedule

The monitoring system may vary depending on the type of wastewater reuse and local conditions. The requirements for individual reclamation systems must be provided by the user. Table 7.12 shows a typical monitoring schedule that could be used for any of the three reclamation systems shown in Figures 7.1, 7.2 and 7.3. Samples for these tests should be taken from valves in the effluent pipeline before the effluent leaves the plant. Temperature, dissolved oxygen, pH, conductivity and turbidity all may be monitored continuously with the results plotted by recorders.

In addition to monitoring effluent water quality, flow rates also must be recorded. Hydraulic loading rates on wells in terms of gallons per day per well are very important. Any loss of loading capacity by any well must be investigated immediately. If a recharge well is losing its recharge ability, try to identify the cause of the problem and select appropriate corrective action.

TABLE 7.12 WATER QUALITY MONITORING SCHEDULE

Grab Sample, Daily	24-hour Composite Sample, Weekly	Grab Sample, Weekly	24-hour Composite Sample, Monthly
Alkalinity	Ammonia Nitrogen	Coliforms	Arsenic
Bicarbonate	Bicarbonate	Color	Barium
COD	Boron	Odor	Copper
Calcium	COD		Lead
Chloride	Cadmium		Mercury
Dissolved Oxygen	Calcium		Silver
	Chloride		
Electrical Conductivity	Chromium		
Magnesium	Cyanide		
	Fluoride		
	Iron		
	MBAS		
	Magnesium		
	Manganese		
	Nitrate Nitrogen		
	Organic Nitrogen		
	Phenol		
	Phosphorus		
	Selenium		
	Sodium		
	Sulfate		

Clogging of the well may be caused by slimes and can be corrected by applying chlorine (10 to 15 mg/*L* in the well) to kill the slimes or by allowing the well to rest, which can dry out or starve some slimes. If activated carbon is used in a treatment process, clogging may be caused by carbon fines (very tiny pieces of carbon). These fines may be removed by passing the water through a sand/anthracite filter.

7.21 Interpretation of Test Results and Follow-up Actions

If pH, dissolved oxygen, chemical oxygen demand, nitrogen compounds, phosphorus, coliforms, or odor standards are not met, then adjustments are needed in the treatment processes. If the concentrations of other water quality indicators exceed standards and cannot be removed by treatment, industrial discharge sites should be tested to see if there is someone discharging excessive quantities into the wastewater collection systems. Whenever one of the standards is not met, *NOTIFY THE USER IMMEDIATELY*. If a blending tank is available, add more fresh water to dilute the effluent.

TABLE 7.11 TROUBLESHOOTING GUIDE

Indicators/Observations	Probable Cause	Check or Monitor	Solutions
PONDS 1. Floatables in effluent	1a. Outlet baffle not in proper location	1a. Visually inspect outlet baffle	*REVIEW CHAPTER 9, Vol. I* 1a. Adjust outlet baffle
	1b. Excessive floatables and scum on pond surface	1b. Visually inspect pond surface	1b. Remove floatables from pond surface using hand rakes or skimmers. Scum can be broken up using jets of water or a motor boat. Broken scum often sinks.
2. Excessive algae in effluent	2. Temperature or weather conditions may favor a particular species of algae.	2. Visually observe effluent or run suspended solids test	2. Operate ponds in series. Draw off effluent from below pond surface by use of a good baffle arrangement.
3. Excessive BOD in effluent	3. Detention time too short, hydraulic or organic overload, poor inlet and/or outlet arrangements and possible toxic discharges	3a. Influent flows 3b. Calculate organic loading 3c. Observe flow thru inlet and outlet structures 3d. Dead algae in effluent	3a. Inspect collection systems for infiltration and correct at source. 3b. Use pumps to recirculate pond contents. 3c. Rearrange inlets and outlets or install additional ones. 3d. Prevent toxic discharges.
SECONDARY CLARIFIERS FOR TRICKLING FILTERS, ROTATING BIOLOGICAL CONTACTORS OR ACTIVATED SLUDGE			*REVIEW CHAPTER 6, Vol. I* *REVIEW CHAPTER 7, Vol. I* *OR* *REVIEW CHAPTERS 8 & 11, Vol. I & II, AND CHAPTER 1*
1. Floatables in effluent	1a. Clarifiers hydraulically overloaded	1a. Visually observe effluent or calculate hydraulic loadings	1a. Install hardware cloth or similar screening device in effluent channels. *REVIEW CHAPTER 5, Vol. I*
	1b. Skimmers not operating properly	1b. Observe skimmer movement at beaching plate	1b. Lower skimmer arm or replace neoprene.
2. Excessive suspended solids in effluent	2a. Clarifiers hydraulically overloaded	2a. See 1a above	2a. See 1a above and review operation of biological treatment process.
	2b. Biological treatment process organically overloaded	2b. Calculate BOD or organic loading	2b. Review operation of biological treatment process.
3. High BOD in effluent	3a. See 2b above	3a. See 2b above	3a. See 2b above
DISINFECTION			*REVIEW CHAPTER 10, Vol. I*
1. Unable to maintain chlorine residual	1a. Chlorinator not working properly	1a. Inspect chlorinator	1a. Repair chlorinator.
	1b. Increase in chlorine demand	1b. Run chlorine demand tests	1b. Increase chlorine dose and/or identify and correct cause of increase in demand.
2. Unable to meet coliform requirements	2a. Chlorine residual too low	2a. See 1 above	2a. See 1 above.
	2b. Chlorine contact time too short	2b. Measure time for dye to pass thru contact basin	2b. Improve baffling arrangement.
	2c. Solids in effluent	2c. Observe solids or run suspended solids test	2c. Install hardware cloth or similar screening device in effluent channels. Review operation of biological treatment process.
	2d. Sludge in contact basin	2d. Look for sludge deposits in contact basin	2d. Drain and clean contact basin.
	2e. Diffuser not properly discharging chlorine	2e. Lower tank water level and inspect	2e. Clean diffuser.
	2f. Mixing inadequate	2f. Add dye at diffuser	2f. Add mechanical mixer or move diffuser.

7.3 SAFETY

Always work with another operator when collecting samples or working around storage reservoirs or blending tanks. Take necessary precautions to avoid slipping or falling into the water and drowning. Pump station safety has been discussed in Chapter 14, "Plant Safety and Good Housekeeping," Vol. II.

A major safety consideration is the health of persons coming in contact with reclaimed water. Be sure the effluent from your wastewater reclamation facility is adequately disinfected at all times. If the effluent ever presents a potential threat to the public's health, *NOTIFY THE USERS IMMEDIATELY*.

7.4 MAINTENANCE

There are very few maintenance considerations except for pumps which are covered in Chapter 15, "Maintenance," Volume II. Metering system maintenance consists mainly of cleaning and visual inspections. Otherwise maintenance means good housekeeping.

7.5 REVIEW OF PLANS AND SPECIFICATIONS

Plans and specifications should be reviewed to insure a piping system with alternate flow paths. If problems develop, there must be a way to pipe the effluent to temporary storage or back to treatment. In other words, there must be an alternate route for the flow.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 429.

7.2A List possible causes of clogging in a recharge well and possible cures for each cause.

7.2B What would you do if reclaimed effluent was being used by industry and one of the water quality standards was not being met?

7.3A Why should you always work with another operator when working around storage reservoirs or blending tanks?

END OF LESSON 1 OF 2 LESSONS
ON
WASTEWATER RECLAMATION

DISCUSSION AND REVIEW QUESTIONS

(Lesson 1 of 2 Lessons)

Chapter 7. **WASTEWATER RECLAMATION**

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. What are some of the limitations of or precautions for direct use of reclaimed wastewater?
2. What would you do if one of your treatment processes failed and you were unable to meet effluent quality standards?
3. What is the purpose of a monitoring program?
4. Why should you be concerned about protecting the public health when operating a wastewater reclamation facility?
5. Why should you look for alternate flow paths when reviewing the plans and specifications for a wastewater reclamation facility?

CHAPTER 7. WASTEWATER RECLAMATION

(Lesson 2 of 2 Lessons)

EFFLUENT DISPOSAL ON LAND

7.6 LAND TREATMENT SYSTEMS

7.60 Description of Treatment Systems

When a high quality effluent or no discharge is required, land treatment offers a means of wastewater reclamation or ultimate disposal. Land treatment systems use soil, plants and bacteria to treat and reclaim wastewaters. They can be designed and operated for the sole purpose of wastewater disposal, for crop production, or for both purposes (Fig. 7.10). In land treatment, effluent is pretreated and applied to land by conventional irrigation methods. When systems are designed for crop production, the wastewater and its nutrients (nitrogen and phosphorus) are used as a resource. This system is then comparable to the reuse systems described in Lesson 1. With either approach, treatment is provided by natural processes (physical, chemical and biological) as the effluent flows through the soil and plants. Part of the wastewater is lost by *EVAPOTRANSPIRATION*[2] and the rest goes back to the *HYDROLOGIC CYCLE*[3] through surface runoff and/or percolation to the groundwater system. Land disposal of wastewater may be done by one of the following methods shown in Figure 7.11.

1. Irrigation,
2. Overland flow, and
3. Infiltration-percolation.

The method of irrigation depends on the type of crop being grown. Irrigation methods include traveling sprinklers, fixed sprinklers, furrow and flooding. Infiltration-percolation systems are not suited for crop growth. Overland flow systems are similar to other treatment processes and have runoff which must either be discharged or recycled in the system. The other systems usually do not have a significant surface runoff. Typical loading rates for these systems are shown in Table 7.13.

Land application systems include the following parts:

1. Treatment before application,
2. Transmission to the land treatment site,
3. Storage,
4. Distribution over site,
5. Runoff recovery system (if needed), and
6. Crop systems.

7.61 Equipment Requirements

Irrigation systems apply water by sprinkling or by surface spreading (Figure 7.12). Sprinkler systems may be fixed or movable. Fixed systems are permanently installed on the ground or buried with sprinklers set on risers that are spaced along pipelines. These systems have been used in all types of terrain. Movable systems include center pivot, side wheel roll, and traveling gun sprinklers.

Surface irrigation systems include flooding, border-check, and ridge and furrow systems. Flooding systems are very similar to overland flow systems except the slopes are nearly level. Border-check systems are simply a controlled flooding system. Ridge and furrow systems are used for row crops such as corn where the water flows through furrows between the rows and seeps into the root zone of the crop.

An overland flow system consists of effluent being sprayed or diverted over sloping terraces where it flows down the hill and through the vegetation. The vegetation provides a filtering action, thus removing suspended solids and insoluble BOD. This system can be operated as a treatment system or, with a recycle system included, can be operated as a disposal system. When operated as a disposal system, the overland flow process is nearly the same as flood irrigation so it will be included with the flood systems in the following paragraphs.

7.62 Sidestreams[4] and Their Treatment

There are two possible sidestreams with land disposal systems. Unlined storage reservoirs will result in wastewater percolating down to groundwater. If the water stored in reservoirs is the final effluent from a treatment plant, percolation down to the groundwater probably is acceptable. However, if the water is untreated or partially treated (primary effluent), the reservoir should be lined or an underground collection system should be installed to collect any percolation or seepage from the reservoir. In some areas percolation may cause a rise in the area's groundwater level. To prevent groundwater problems, a seepage ditch may be built around the outside of the reservoir. This ditch should be located somewhat lower than the bottom of the reservoir. Wastewater that percolates through the reservoir bottom is collected in the ditches. This water can be pumped back into the reservoir. The groundwater table also could be lowered by a series of shallow wells with water being pumped out as necessary. Lowering of the groundwater could result in increased percolation rates.

The other major sidestream is surface runoff. Runoff quantities vary depending on the type of irrigation system used. In all systems provisions should be made for collecting runoff and returning this flow to be reapplied. In some locations runoff water can be discharged to surface water. Discharge is the preferred approach due to saving costs and minimizing operational problems.

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[2] *Evapotranspiration (e-VAP-o-tran-spi-RAY-shun). The total water removed from an area by transpiration (plants) and by evaporation from soil, snow and water surfaces.*

[3] *Hydrologic Cycle (HI-dro-loj-ic). The process of evaporation of water into the air and its return to earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement and runoff into rivers, streams and the ocean.*

[4] *Sidestream. Wastewater flows that develop from other storage or treatment facilities. This wastewater may or may not need additional treatment.*

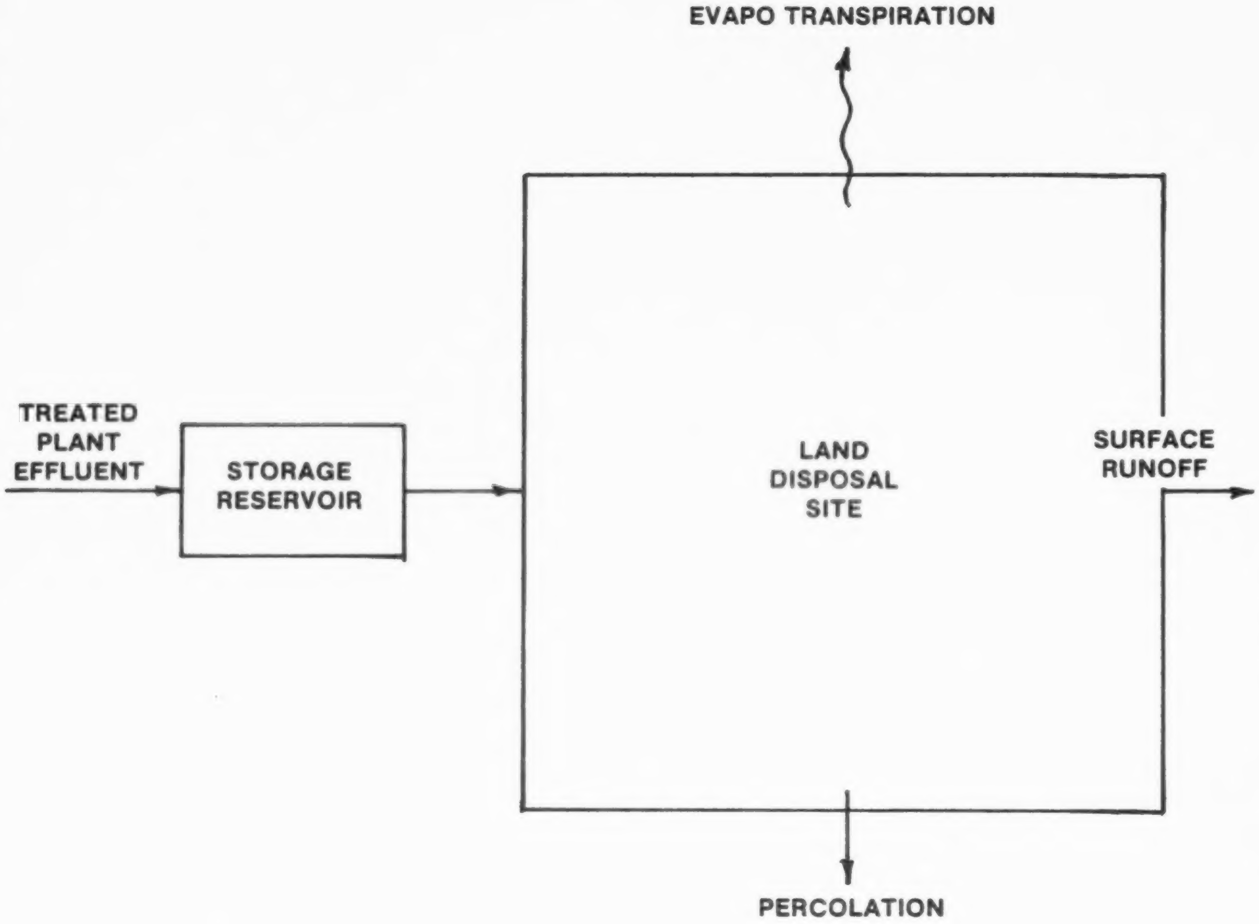
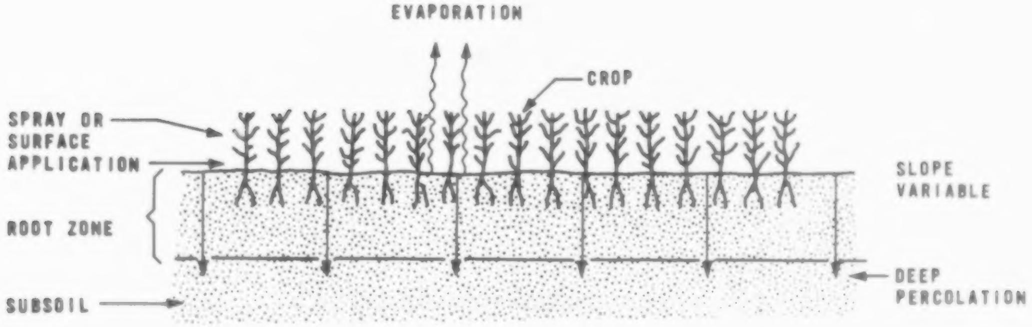
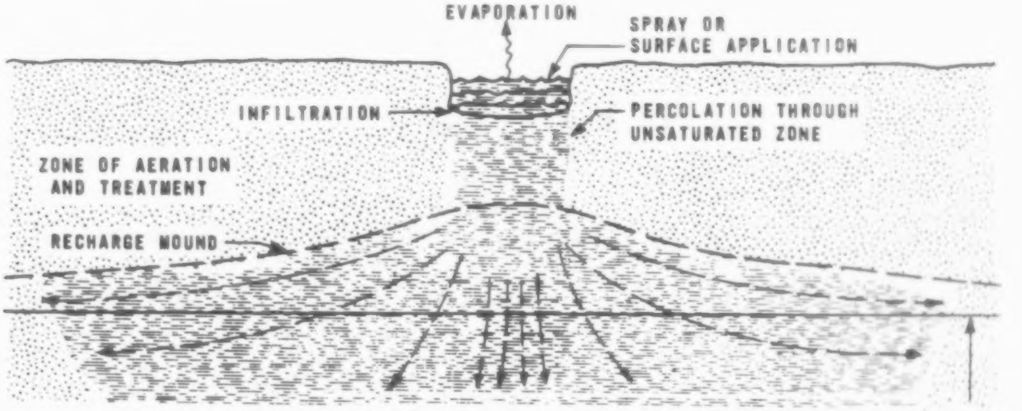

EVAPO TRANSPIRATION
TREATED PLANT EFFLUENT
STORAGE RESERVOIR
LAND DISPOSAL SITE
SURFACE RUNOFF
PERCOLATION

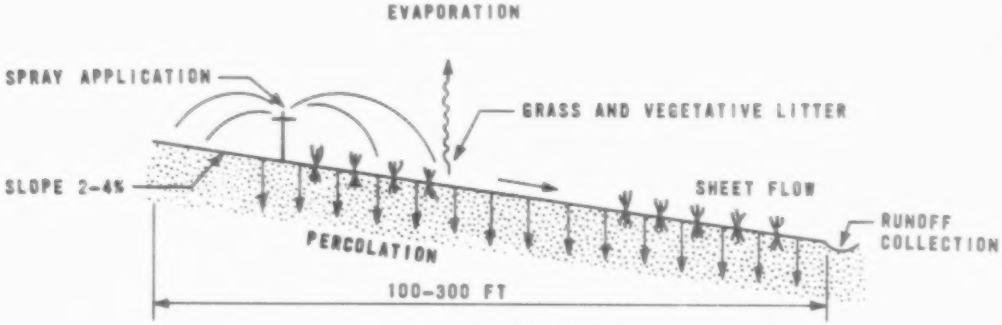
Fig. 7.10 Land disposal system schematic


EVAPORATION
CROP
SPRAY OR SURFACE APPLICATION
ROOT ZONE
SLOPE VARIABLE
DEEP PERCOLATION
SUBSOIL

(a) IRRIGATION


EVAPORATION
SPRAY OR SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
ZONE OF AERATION AND TREATMENT
RECHARGE MOUND
ORIGINAL WATER TABLE

(b) INFILTRATION-PERCOLATION


EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-4%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100-300 FT

(c) OVERLAND FLOW

Fig. 7.11 Methods of land application

(From *COSTS OF WASTEWATER TREATMENT BY LAND APPLICATION* by Pound, C.E., et al, U.S. Environmental Protection Agency, Washington, D.C., 20460, EPA-430/9-75-003, June 1975.)

TABLE 7.13 TYPICAL LOADINGS FOR IRRIGATION, INFILTRATION-PERCOLATION, AND OVERLAND FLOW SYSTEMS[a]

Factor	Irrigation Low-rate	Irrigation High rate	Infiltration-Percolation	Overland flow
Liquid loading rate, in/wk	0.5 to 1.5	1.5 to 4.0	4 to 120	2 to 9
Annual application, ft/yr[c]	2 to 4	4 to 18	18 to 500	8 to 40
Land required for 1-MGD flow rate, acres[d,e]	280 to 560	62 to 280	6 to 62	28 to 140
Application techniques	Spray or surface		Usually surface	Usually surface
Vegetation required	Yes	Yes	No	Yes
Crop production	Excellent	Good/fair	Poor/none	Fair/poor
Soils	Moderately permeable soils with good productivity when irrigated		Rapidly permeable soils, such as sands, loamy sands, and sandy loams	Slowly permeable soils such as clay loams and clays
Climatic constraints	Storage often needed		Reduce loadings in freezing weather	Storage often needed
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation
Expected treatment performance				
BOD and SS removal	98 + %		85 to 99%	92 + %
Nitrogen removal	85 + %[d]		0 to 50%	70 to 90%
Phosphorus removal	80 to 99%		60 to 95%	40 to 80%

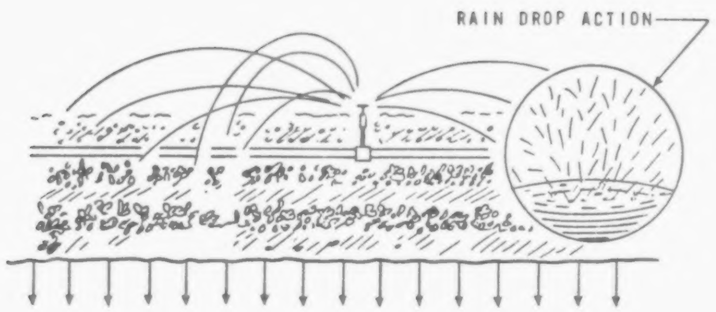
[a] *COSTS OF WASTEWATER TREATMENT BY LAND APPLICATION* by Pound, C.E. et al, U.S. Environmental Protection Agency, Washington, D.C., 20460, EPA-430/9-75-003, June 1975.

[b] in/wk × 2.54 = cm/wk

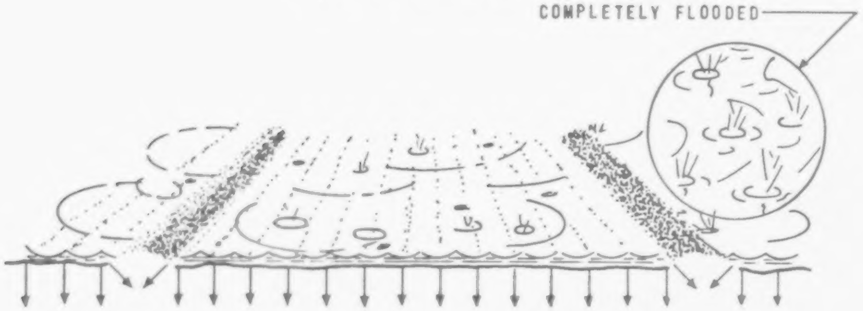
[c] ft/yr × 0.3 = m/yr

[d] Dependent on crop uptake

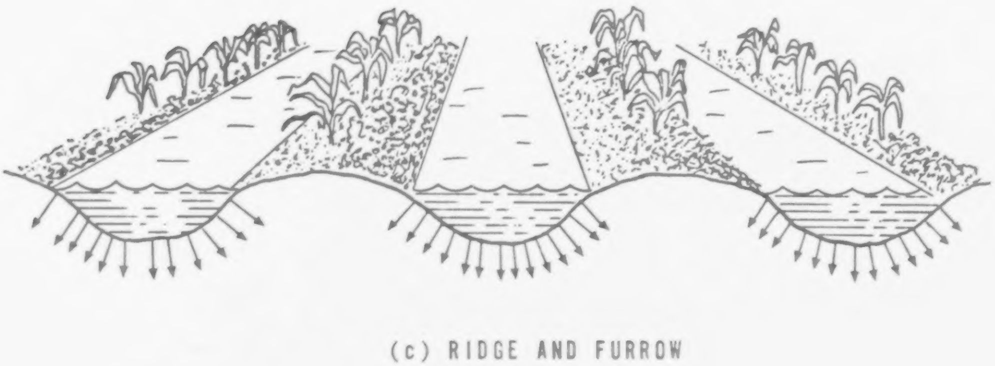
[e] acres × 0.00107 = hectares for 1 cu m/day
or
acres × 9.24 = hectares for 1 cu m/sec


RAIN DROP ACTION

(a) SPRINKLER


COMPLETELY FLOODED

(b) FLOODING



(c) RIDGE AND FURROW

Fig. 7.12 Irrigation techniques

(From *EVALUATION OF LAND APPLICATION SYSTEMS* by Pound, C.E., et al, U.S. Environmental Protection Agency, Washington, D.C. 20460, EPA 430/9-74-015, September 1974.)

7.63 Limitations of Land Treatment

Problems encountered using land treatment systems usually involve soil problems and weather conditions. If proper care is not taken, the soils can lose their ability to percolate applied water. During the cold winter season, plants and crops will not grow. Under these conditions no water will be treated by transpiration processes. Also, precipitation can soak the soil so no wastewater can be treated. Provisions must be made to store wastewater during cold and wet weather.

One of the most common land treatment problems is the sealing (water won't percolate) of the soil by suspended solids in the final effluent. These solids are deposited on the surface of the soil and form a mat which prevents the percolation of water down through the soil. There are three possible solutions to this problem:

1. Remove the suspended solids from the effluent,
2. Apply water intermittently and allow a long enough drying period for the solids mat to dry and crack, or
3. Disc or plow the field to break the mat of solids.

Another serious problem is the buildup of salts in the soil. If the effluent has a high chloride content, there can be enough salts in the soil within one year to create a toxic condition to most grasses and plants. To overcome salinity problems:

1. Leach out the salts by applying fresh water (not effluent), or
2. Rip up the field and turn it over to a depth of 4 to 5 feet (1.2 to 1.5 meters).

The severity of both soil sealing due to suspended solids and salinity problems due to dissolved solids depends on the type of soil in the disposal area. These problems are more difficult in clay soils than in sandy soils.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 430.

7.6A Define the terms evapotranspiration and hydrologic cycle.

7.6B List the three methods by which land disposal of wastewater is accomplished.

7.6C What are the major parts of a land application system?

7.6D A plot of land 2000 feet long by 1000 feet wide is used for a land disposal system. If 1 million gallons is applied to the land during a 24-hour period, calculate the hydraulic loading in:

1. MGD per acre, and
2. Inches per day.

7.7 OPERATING PROCEDURES

The operating procedures described below apply to a spray irrigation system. This system is for an area where crops are to be grown. The operating procedures for this type of system are more complex than the other systems. The procedures are explained first and then an example is presented to show how to use the procedures.

7.70 Pre-start Checklist

Table 7.14 consists of a list of items that should be checked before starting a land disposal system.

7.71 Start-up

1. Determine need to irrigate. The amount of water that can be applied depends on the type of crop. Some crops require a lot of water while other crops will not tolerate any excess water. The procedures in this section are prepared to help you determine when you should irrigate and how much water should be applied. *THESE PROCEDURES ARE BASED ON SOIL CONDITIONS AND MAY REQUIRE ADJUSTMENT BASED ON THE TYPE OF CROP BEING IRRIGATED.* The chart shown on Table 7.15 will aid in determining if you need to irrigate based on soil conditions. To use this table you must first determine the type of soil you are irrigating. Walk around the field and try to identify the different types if more than one type of soil is present. Pick up a handful of soil and examine the grains or particles. Small, hard, tiny particles indicate a sandy soil. Very fine, soft, smooth particles signify a clay soil. Once you've identified the type of soil, the moisture content can be estimated by squeezing the soil together in your hand. The wetter the soil, the more likely the soil will stick or cling together. By the way the soil sticks together and the type of soil, you can estimate when the available moisture content drops to 50 percent or less. Irrigate when the moisture content is 50 percent or less.

   Soils vary throughout an area of land and some areas need irrigating before others. Many farmers have specific areas in their fields which they call "hot spots." Due to soil characteristics or other reasons, these areas dry out faster than the rest of the field. Whenever the soil will not form a ball when squeezed together or crops start to show signs of stress due to lack of water, this is the time to irrigate.

2. Determine amount of moisture to apply using Table 7.16. To use this table, determine the soil type by examining a handful of soil as described in Step 1. The root zone depth is determined by the type of crop. If necessary, dig down to determine how far down the roots are growing. By the use of Table 7.15, you can estimate the percent of available moisture remaining in the soil before irrigation. Knowing the percent available moisture in the soil before irrigation, you can determine the net inches of water to apply this time when you are irrigating from Table 7.16.
3. Determine the time required to apply one inch (2.5 cm) of water from Figures 7.13 or 7.14. Figure 7.13 is used for small areas (up to 60 acres) and Figure 7.14 is used for larger areas (over 60 acres). To use the tables determine (1) the area of land you wish to irrigate and (2) the capacity of your irrigation system in gallons per minute. By starting at the bottom of the figure with the known area, draw a line vertically upward. Next draw a line from the system capacity on the left, horizontally to the right. Where these two lines intersect is the time required to apply one inch of water to the area being irrigated.
4. Multiply time required to apply one inch (2.5 cm) of water by the inches of moisture to apply to determine the total run time for the irrigation system. After you have determined the net inches of water you wish to apply from Table 7.16 (Step 2), multiply the net inches times the time required (Figures 7.13 and 7.14) to determine the total irrigation time.

   If you need help determining soil types, irrigation requirements, soil moisture content, types of crops to plant, salt tolerance of plants, depth of root zone and any fertilizer needs, contact your local farm adviser. In many areas an expert adviser is available free of charge through some agency of the federal, state or local government.

TABLE 7.14 PRE-START CHECKLIST[a]

Check Every Time Pump Is Started	Check At The Beginning Of The Season	
		Electric Motors
	______	Replace winter lubricant.
	______	Oil bath bearings. Drain oil and replace with proper weight of clean oil.
	______	Grease lube bearings. If grease gun is used, be sure old grease is purged through outlet hole.
______		Before turning on switch, have power company check voltage.
	______	Check for proper rotation of motor and pump.
______	______	Check fuses to make sure they are still good.
______	______	Check electrical contact points for excessive corrosion.
______	______	Physically inspect for rodent and insect invasion.
		Pumps
	______	Replace oil or grease with proper weight bearing lubricant.
______	______	Tighten packing gland to proper setting.
______	______	Check discharge head, discharge check valve, and suction screen thoroughly for foreign matter.
______	______	Pump shaft should turn freely without noticeable dragging.
		Aluminum Pipe
	______	If you didn't properly handle and store aluminum pipe or tubing last fall, make a mental note to do that at the end of this growing season. Always carefully drain aluminum tubing or pipe when you are finished using it. Aluminum pipe bends very easily. If you pick up a length of pipe that is half full of water and has one end plugged, you will bend the pipe. Flush out the pipe to clean it, drain the pipe, place the pipe on a long-bed trailer for transport, and then store the pipe on racks until you are ready to use the pipe next season.
	______	Inspect pipe ends to make certain that no damage has occurred. Ends should be round for best operation. A slightly tapered wooden plug of the proper diameter can be used to round out the ends. The diameter of aluminum pipe varies from 2 to 12 inches (50 to 300 mm).
	______	Check pipe for pit corrosion of tubing. If "spots" are in evidence, contact the aluminum pipe supplier for advice.
	______	Inspect pipe gaskets, couplers (irrigation pipe couplings), and gates to find those in need of replacement.
______	______	Check pipeline to see that all couplers are still fastened, pipe supports haven't fallen over, and gates and valves are still open.
______	______	Pipe makes an excellent nesting area for small animals. Flush out the pipeline before installing the end plug. Make sure you are away from power lines when you raise the pipe to drain water from the pipe.
		Sprinkler Systems
	______	Sprinkler bearing washers should be replaced if there is indication of wear.
______	______	Visually check all moving parts, seals, bearings and flexible hose for replacement or repair.
______	______	Check to see that hose is laid out straight or on a long radius for turns. Be sure there are no kinks in the hose. There should be sufficient hose at the end of the sprinkler to act as a brake or to hold back the sprinkler system initially as it drags the hose through the field. Also check earth anchors.
______	______	If possible, operate the system to check speed adjustment, alignment, and safety switch mechanisms.
______	______	Check sprinkler oscillating arm for proper adjustment. If damage has occurred to the sprinkler oscillating arm, the arm should be replaced or bent back to the correct angle. Your dealer can help in correcting a damaged arm. The angle of water-contact surface, if not correct, will change the turning characteristics of the sprinkler. Excessive wear of sprinkler nozzles can be checked with proper size drill bit.

REMEMBER, inspection and corrective maintenance now may save considerable time and money later.

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[a] *WATER RESOURCES MANUAL*, Noram, Edward (editor), permission of The Irrigation Association, Silver Spring, Maryland 20906.

TABLE 7.15 FEEL AND APPEARANCE GUIDE FOR DETERMINING SOIL MOISTURE[a]

The chart below is very useful in knowing how much available moisture is in your soil. Although the plant's daily moisture use may range from 0.1 inches to 0.4 inches per day (0.25 to 1.0 cm), it will average about 0.20 inches (0.5 cm) per day, and 0.25 inches (0.6 cm) per day during hot days.

Moisture Condition	Percent of available moisture remaining in soil, %	SOIL TEXTURE		
		Sands-Sandy Loams	**Loams-Silt Loams**	**Clay Loams-Clay**
Dry	Wilting point	Dry loose, flows through fingers.	Powdery, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked; difficult to break down into powdery condition.
Low	50% or less		Will form a weak ball when squeezed but won't stick to tools.	Pliable, but not slick, will ball under pressure — sticks to tools.
TIME TO IRRIGATE WHEN AVAILABLE MOISTURE IS 50 PERCENT OR LESS				
Fair	50 to 75%	Tends to ball under pressure but seldom will hold together when bounced in the hand.	Forms a ball somewhat plastic, will stick slightly with pressure. Doesn't stick to tools.	Forms a ball, will ribbon out between thumb and forefinger, has a slick feeling.
Good	75 to 100%	Forms a weak ball, breaks easily when bounced in the hand, can feel moistness in soil.	Forms a ball, very pliable, slicks readily, clings slightly to tools.	Easily ribbons out between thumb and forefinger, has a slick feeling, very sticky.
Ideal	Field Capacity 100%	Soil mass will cling together. Upon squeezing, outline of ball is left on hand.	Wet outline of ball is left on hand when soil is squeezed. Sticks to tools.	Wet outline of ball is left on hand when soil is squeezed. Sticky enough to cling to fingers.

[a] *WATER RESOURCES MANUAL*, Norum, Edward (editor), permission of Sprinkler Irrigation Association, Silver Spring, Maryland 20906.

5. Check pump discharge check valve and suction screen for foreign matter.
6. Check pipeline to see that all couplings are still fastened, blocks or pipe supports haven't fallen over, and gates and valves are open.
7. Start pump.
8. Inspect the irrigation system to be sure everything is working properly.

EXAMPLE

Using the procedures outlined in this section, this example shows how to determine the total time to irrigate.

1. Determine need to irrigate. A loamy soil formed a weak ball when squeezed. Table 7.15 indicates the moisture condition is low (50% or less) and that it is time to irrigate.
2. The loamy (light sandy) soil has a crop with a root-zone depth of 3 feet (0.9 m) and 50 percent of the available moisture is retained in the soil at irrigation. Table 7.16 indicates that 1.5 inches (3.8 cm) of water should be applied to the soil.
3. The land to be irrigated is a 40-acre plot and the pump has a capacity of 1000 GPM. From Figure 7.13, find 40 acres across the bottom and draw a line vertically upward to the top. Find the system capacity of 1000 GPM along the left side and draw a line horizontally to the right. These lines intersect between the diagonal lines labeled 15 hours and 20 hours at approximately 18 hours. Therefore we should irrigate for 18 hours to apply one inch of water.
4. Determine the total time to irrigate.

Time, hours = Time, (hr) to irrigate one inch × Amount to apply, in

= 18 hours/inch × 1.5 inches

= 27 hours

7.72 Normal Operation

1. Run the pump or pumps the time determined by Step 4 of the start-up procedure and as shown in the example.
2. Turn the pump off earlier if water begins to pond on the fields.

TABLE 7.16 AMOUNT OF MOISTURE TO APPLY TO VARIOUS SOILS UNDER DIFFERENT MOISTURE RETENTION CONDITIONS[a]

Soil Type	Root Zone Depth	Available Moisture Plants Will Use	Net Inches to Apply Per Irrigation With Various Percents Available Moisture Retained in the Soil before Irrigation		
			Percent Available Moisture before Irrigation		
	Feet	Inches	67%	50%	33%
Light Sandy	1	1.00	0.33	0.50	0.67
	1½	1.50	0.50	0.75	1.00
	2	2.00	0.56	1.00	1.33
	2½	2.50	0.83	1.25	1.67
	3	3.00	0.99	1.50	2.00
Medium	1	1.69	0.57	0.85	1.13
	1½	2.53	0.84	1.26	1.70
	2	3.38	1.11	1.69	2.26
	2½	4.21	1.39	2.11	2.82
	3	5.06	1.67	2.53	3.38
Heavy	1	2.39	0.79	1.20	1.59
	1½	3.58	1.18	1.79	2.38
	2	4.78	1.58	2.39	3.25
	2½	5.97	1.97	2.98	3.97
	3	7.17	2.36	3.58	4.77

[a] *WATER RESOURCES MANUAL*, Norum, Edward (editor), permission of Sprinkler Irrigation Association, Silver Spring, Maryland 20906.

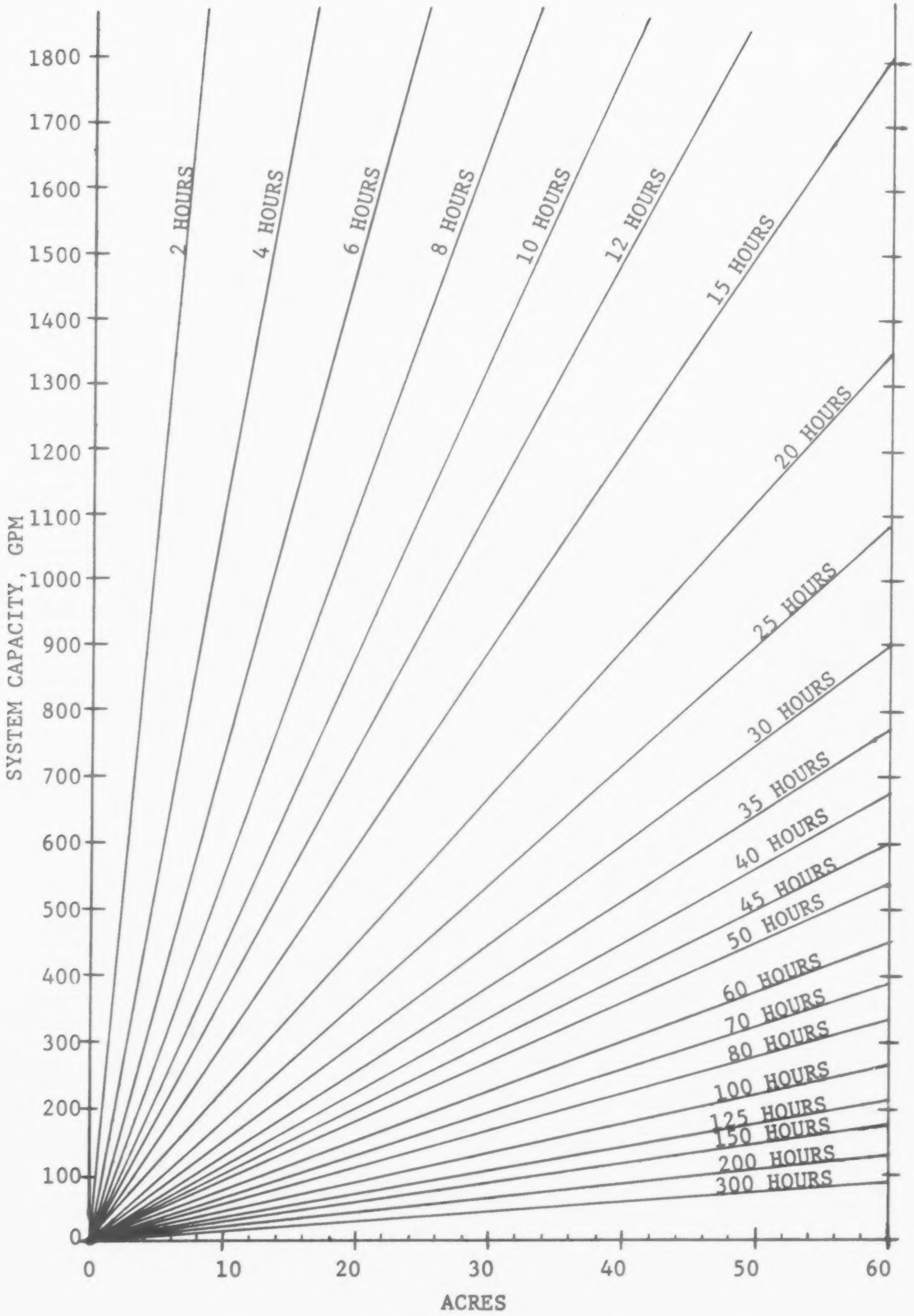

Fig. 7.13 Time required to apply one inch (2.5 cm) of water on small acreages
(From *WATER RESOURCES MANUAL*, Norum, Edward (editor), permission
of Sprinkler Irrigation Association, Silver Spring, Maryland.)

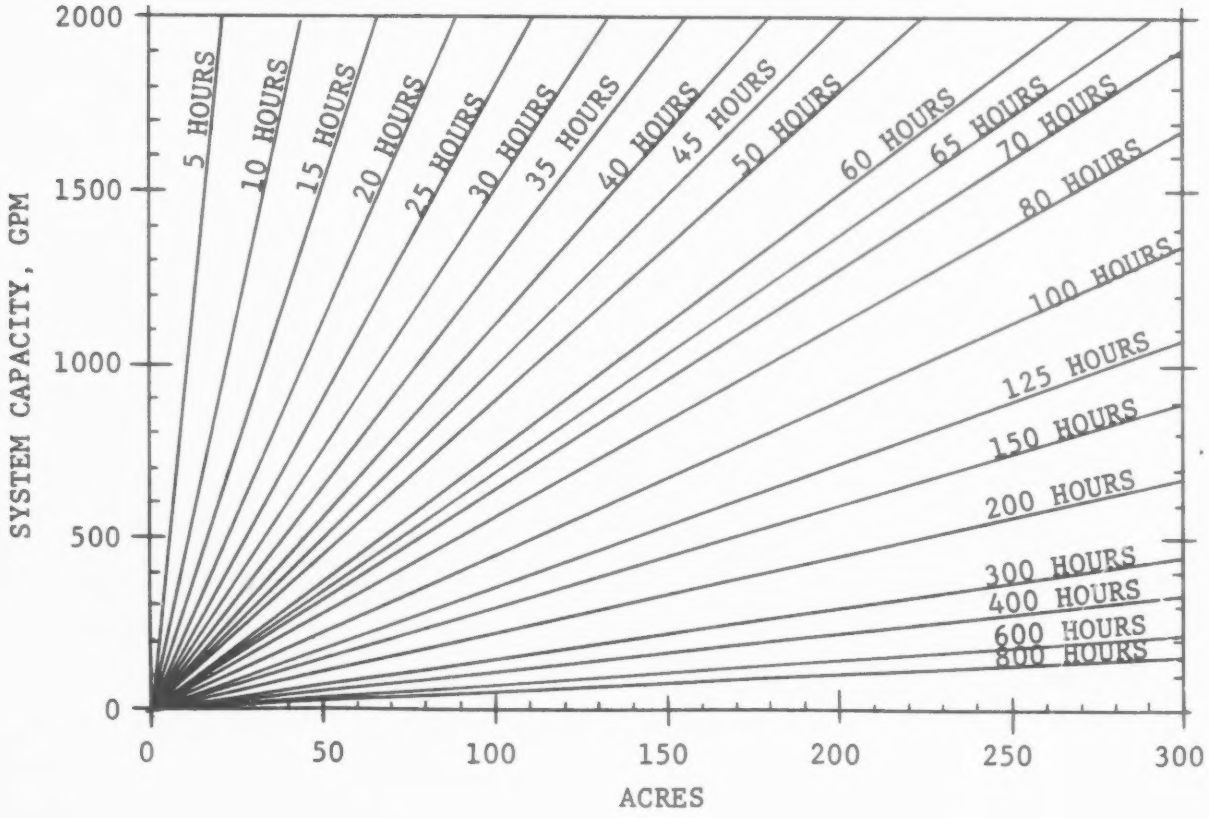

Fig. 7.14 Time required to apply one inch (2.5 cm) of water on large acreages

(From *WATER RESOURCES MANUAL*, Norum, Edward (editor), permission of Sprinkler Irrigation Association, Silver Spring, Maryland.)

7.73 Shutdown

This shutdown procedure applies to the end of season shutdown.

1. Drain all lines.
2. Plug open ends of pipelines.
3. Lubricate motors and pumps for winter.
4. Store small movable materials and equipment.
5. Store aluminum tubing or piping.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 430.

7.7A List the major items of equipment that should be inspected before starting a spray irrigation system.

7.7B Determine the time required to irrigate 30 acres of a medium-type soil where the root-zone depth is 2 feet and 50 percent of the available moisture is retained in the soil at irrigation. Pump capacity is 1200 GPM. Use the figures and tables in this lesson to answer this question.

7.74 Operational Strategy

Physical Control. The main objective of a land disposal system is to dispose of effluent without harming surface waters or creating nuisance conditions. An irrigation system can be designed and operated to produce a crop. The sale of this crop then helps reduce treatment costs. Physical control is then used to dispose of effluent at the highest rate possible without damaging the crop. For all types of land disposal systems, physical controls consist of valves and/or gates which are used to direct treated effluent to different disposal areas.

Process Control. There are three areas of process control; storage reservoirs, runoff and seepage water recycle systems, and systems where crops are grown. The first is the storage reservoir. The reservoir usually will have been provided with aeration or mixing devices. These devices may be operated full time or for a limited time each day by using timers. The correct time to operate is determined by measuring the dissolved oxygen (DO) content at several points in the reservoir. A minimum of 4 points should be sampled. An example showing six sampling locations is illustrated in Figure 7.15.

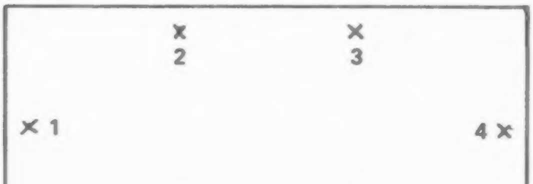

Fig. 7.15 Possible reservoir sampling locations

Each sample should have at least 0.4 mg/*L* of DO and the average of all samples should be at least 0.8 mg/*L*. Two sample sets of test results are shown below:

Set 1 —

Sample No.	**mg/L DO**
1	1.2
2	1.8
3	2.0
4	1.6
5	0.2
6	0.4

$$\text{Average} = \frac{7.2}{6} = 1.2 \text{ mg}/L$$

Set 2 —

Sample No.	**mg/L DO**
1	1.0
2	0.4
3	0.8
4	1.4
5	0.6
6	1.2

$$\text{Average} = \frac{5.4}{6} = 0.90 \text{ mg}/L$$

Set 1 does not meet the requirements. The average DO is 1.2 mg/*L* which is good, but one sample (#5) is 0.2 mg/*L* which does not meet the minimum requirement. This result indicates that there is adequate aeration but either a portion of the system is not operating properly or the reservoir is not being adequately mixed.

Even though Set 2 has a lower average DO than Set 1, the average is greater than 0.8 and all samples are 0.4 mg/*L* or greater. Therefore, Set 2 is acceptable.

The second area of process control is the runoff and seepage water recycle systems. These recycle systems may not be necessary, depending on the particular application. For example, the storage reservoir may be lined so there would be no seepage water to recycle. Sprinkler systems that are carefully controlled will have no significant runoff. Your goal is to dispose of as much water as possible without causing runoff and seepage from the disposal area. This is done to reduce recycle pumping costs. The reduction in seepage and runoff is accomplished by taking more care in applying effluent and turning off sprinklers or closing gates when water begins to stand in the field.

The third area of process control applies to those systems where crops are grown. In dry climates such as found in the southwestern states and western mountain states, farmers who irrigate are concerned with saline and alkali soils. Some minerals are found in the effluent may cause a decrease in crop production in soils of this type. Analyses and irrigation practices for these areas are described in detail in the U.S. Department of Agriculture Handbook No. 60, *SALINE AND ALKALI SOILS*.[5] A diagram for the classification of irrigation waters (taken from Handbook No. 60) is shown on Figure 7.16.

A simplified version of this table with other critical constituents (substances) is shown on Table 7.17.

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[5] **DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALINE SOILS,** ***Richards, L.A. (editor), Agricultural Handbook No. 60, U.S. Department of Agriculture, Washington, D.C.***

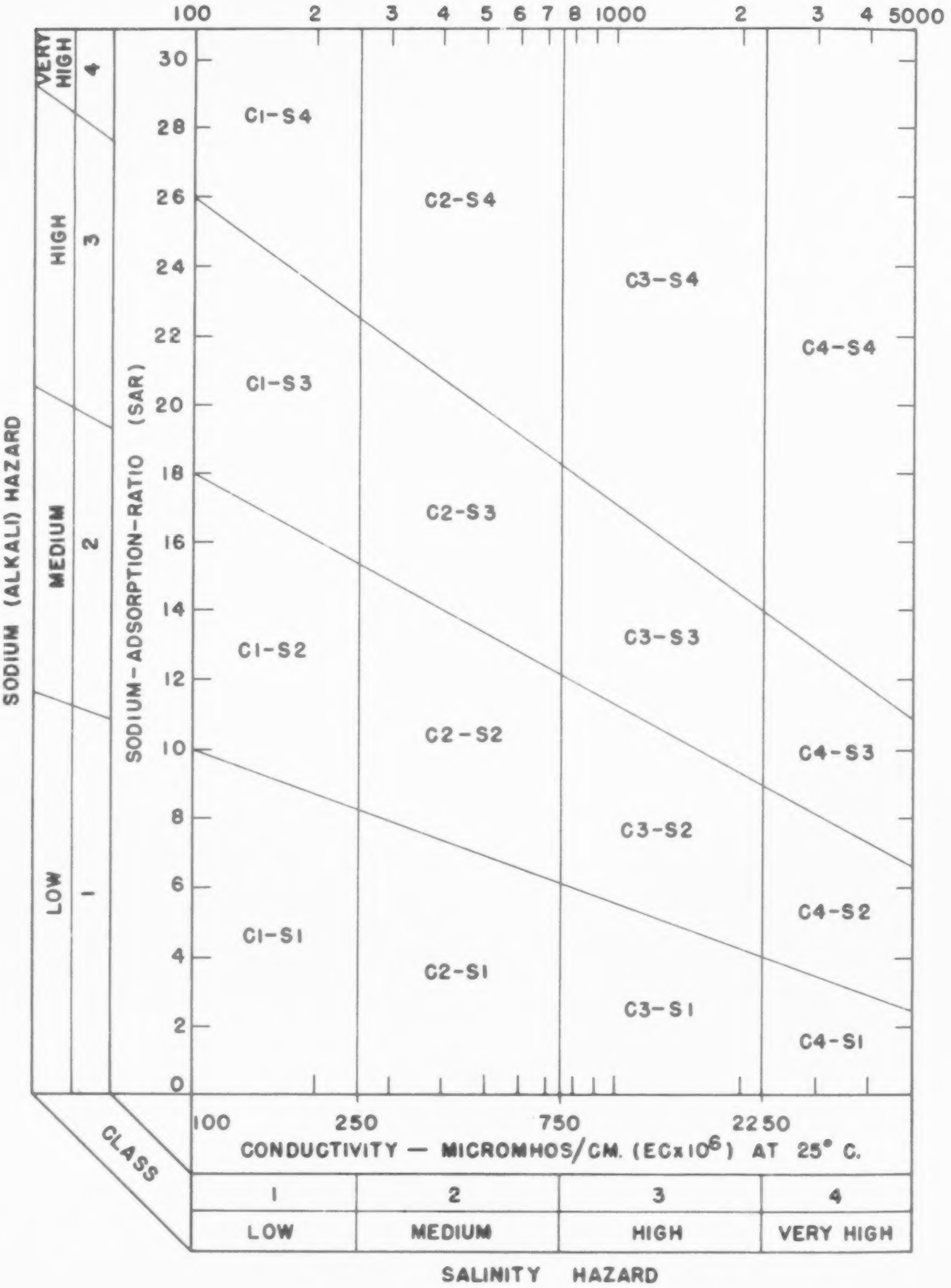

Fig. 7.16 Diagram for the classification of irrigation waters

(From *DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALINE SOILS*, Richards, L.A. (editor), Agricultural Handbook No. 60, U.S. Department of Agriculture, Washington, D.C.)

TABLE 7.17 CLASSIFICATION OF IRRIGATION WATERS[a]

	Class I	Class II	Class III
	Excellent to Good	Good to Injurious	Injurious to Unsatisfactory
Chemical Properties	"Suitable under most conditions"	"Suitability dependent on soil crop, climate and other factors"	"Unsuitable under most conditions"
Total dissolved solids (mg/*L*)	Less than 700	700-2,000	More than 2,000
Chloride (mg/*L*)	Less than 175	175-350	More than 350
Sodium (percent of base constituents)	Less than 60	60-75	More than 75
Boron (mg/*L*)	Less than 0.5	0.5-2.0	More than 2.0

[a] *DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALINE SOILS*, Richards, L.A. (editor), Agricultural Handbook No. 60, U.S. Department of Agriculture, Washington, D.C.

Your local U.S. Department of Agriculture, Soil Conservation Service office, can provide a list of crops that can be irrigated with Class II and Class III water.

There is nothing that can be done that is economically feasible to control the concentration of these constituents. If one of the constituents exceeds the Class I limit, the crop should be changed to one that is more tolerant. Special agricultural practices can be used to minimize the effects of these constituents. These practices vary from one local area to another. The local soil conservation service office and farm adviser can assist by providing information appropriate to the area.

Important observations and interpretations were discussed earlier for determining when to irrigate. The most important observations in a system where crops are grown and surface runoff is not allowed are observing ponding or runoff. When this occurs, either the application amount was excessive or the rate of application was greater than the soil infiltration rate.

Visual appearance of the crop being grown is extremely important. Discoloration in plant leaves can indicate excess water (poor drainage) or a nutrient or mineral deficiency. Your local farm adviser can assist in diagnosing the problems.

Observations are critical in storage reservoirs. Odors can result if effluent treatment was inadequate and/or if insufficient aeration is provided to the reservoir.

7.75 Emergency Operating Procedures

Loss of power will disrupt the sprinkler systems the most since pumping is required (assuming electrical motors for pumps). If power is lost, the effluent is retained in the storage reservoir. Gravity-flow flood irrigation systems won't be affected during power outages.

Loss of other treatment units is generally not a problem for a few days. Longer downtimes may result in an overloaded and an odorous storage reservoir and possible odors at the disposal area.

7.76 Troubleshooting Guide (Table 7.18)

TABLE 7.18 TROUBLESHOOTING GUIDE

Indicators/Observations	Probable Cause	Check or Monitor	Solutions
1. Water ponding in irrigated area where ponding normally has not been observed.	1a. Application rate is excessive. 1b. If application rate is normal, drainage may be inadequate. 1c. Broken pipe in distribution system.	1a. Application rate. 1b(1) Seasonal variation in groundwater level. 1b(2) Operability of any drainage wells. 1b(3) Condition of drain tiles. 1c. Leaks in system.	1a. Reduce rate to normal value. 1b(1) Irrigate portions of the site where groundwater is not a problem or store wastewater until level has dropped. 1b(2) Repair drainage wells or increase pumping rate. 1b(3) Repair drain tiles 1c. Repair pipe.
2. Lateral aluminum distribution piping deteriorating.	2a. Effluent permitted to remain in aluminum pipe too long causing electrochemical corrosion. 2b. Dissimilar metals (steel valves and aluminum pipe).	2a. Operating techniques. 2b. Pipe and valve specifications.	2a. Drain aluminum lateral lines except when in use. 2b. Coat steel valves or install cathodic or anodic protection.
3. No flow from some sprinkler nozzles.	3. Nozzle clogged with particles from wastewater due to lack of screening at inlet side of irrigation pumps.	3. Screen may have developed hole due to partial plugging of screen.	3. Repair or replace screen.
4. Wastewater is running off of irrigated area.	4a. Sodium adsorption ratio of wastewater is too high and has caused clay soil to become impermeable. 4b. Soil surface sealed by solids. 4c. Application rate exceeds infiltration rate of soil. 4d. Break in distribution piping.	4a. Sodium adsorption ratio (SAR) should be less than 9. 4b. Soil surface. 4c. Application rate. 4d. Leaks in distribution piping.	4a. Feed calcium and magnesium to adjust SAR. 4b. Strip crop area. 4c. Reduce application rate until compatible with infiltration rate. 4d. Repair breaks.

TABLE 7.18 TROUBLESHOOTING GUIDE (Continued)

Indicators/Observations	Probable Cause	Check or Monitor	Solutions
	4e. Soil permeability has decreased due to continuous application of wastewater.	4e. Duration of continuous operation on the given area.	4e. Each area should be allowed to rest (2-3 days) between applications of wastewater to allow soil to drain.
	4f. Rain has saturated soil.	4f. Rainfall records.	4f. Store wastewater until soil has drained.
5. Irrigated crop is dead.	5a. Too much (or not enough) water has been applied.	5a. Water needs of specific crop versus application rate.	5a. Reduce (or increase) application rate.
	5b. Wastewater contains excessive amount of toxic elements.	5b. Analyze wastewater and consult with county agricultural agent.	5b. Eliminate industrial discharges of toxic materials.
	5c. Too much insecticide or weed killer applied.	5c. Application of insecticide or weed killer.	5c. Proper control of application of insecticide or weed killer.
	5d. Inadequate drainage has flooded root zone of crop.	5d. Water ponding.	5d. (See Item 1)
6. Growth of irrigated crop is poor.	6a. Too little nitrogen (N) or phosphorus (P) applied.	6a. N and P quantities applied — check with county agricultural agent.	6a. If increased wastewater application rates are not practical, supplement wastewater N or P with commercial fertilizer.
	6b. Timing of nutrient application not consistent with crop need. (Also, see 5a — 5c)	6b. Consult with county agricultural agent.	6b. Adjust application schedule to meet crop needs.
7. Irrigation pumping station shows normal pressure but above normal flow.	7a. Broken main, lateral, riser, or gasket.	7a. Inspect distribution system for leaks.	7a. Repair leak.
	7b. Missing sprinkler head or end plug.	7b. Inspect distribution system for leaks.	7b. Repair leak.
	7c. Too many laterals on at one time.	7c. Number of laterals in service.	7c. Make appropriate valving changes.
8. Irrigation pumping station shows above average pressure but below average flow.	8. Blockage in distribution system due to plugging sprinklers, valves, screens, or frozen water.		8. Locate blockage and eliminate.
9. Irrigation pumping station shows below normal flow and pressure.	9a. Pump impeller is worn.	9a. Pump impeller.	9a. Replace impeller (See Section 25.11, "Review of Plans and Specifications," No. 5.)
	9b. Partially clogged inlet screen.	9b. Screen.	9b. Clean screen.
10. Excessive erosion occuring.	10a. Excessive application rates.	10a. Application rate.	10a. Reduce application rate.
	10b. Inadequate crop cover.	10b. Condition of crop cover.	10b. (See Items 5 and 6)
11. Odor complaints.	11a. Wastewater turning septic during transmission to irrigated site and odors being released as it is discharged to pretreatment.	11a. Sample wastewater as it leaves transmission system.	11a. Contain and treat off-gases from discharge point of transmission system by covering inlet with building and passing off-gases through deodorizing system.
	11b. Odors from storage reservoirs.	11b. DO in storage reservoirs.	11b. Improve pretreatment or aerate reservoirs.
12. Center pivot irrigation rigs stuck in mud.	12a. Excessive application rates.		12a. Reduce application rates.
	12b. Improper tires or rigs.		12b. Install tires with higher flotation capabilities.
	12c. Poor drainage.		12c. Improve drainage (See Item 1b).
13. Nitrate concentration of groundwater in vicinity of irrigation site is increasing.	13a. Application of nitrogen is not in balance with crop needs.	13a. Check lbs/acre/yr of nitrogen being applied with needs of crops.	13a. Change crop to one with higher nitrogen needs.
	13b. Nitrogen being applied during periods when crops are dormant.	13b. Application schedules.	13b. Apply wastewater only during periods of active crop growth.
	13c. Crop is not being harvested and removed.	13c. Farming management.	13c. Harvest and remove crop.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 430.

7.7C What is the main objective of a land disposal system?

7.7D List the three main areas of process control in a land disposal system.

7.7E How many points in a storage reservoir should be sampled for DO?

7.7F What are the minimum recommended DO requirements for a storage reservoir?

7.7G What are the probable causes of water ponding in an irrigated area where ponding normally has not been observed?

7.8 MONITORING

7.80 Monitoring Schedule

The four monitoring areas for an irrigation system where crops are grown are: effluent, vegetation, soils, and groundwater (or collected seepage). This is reduced to the two areas of effluent and groundwater for systems where crops are not grown. Wells should be monitored to identify any adverse effects on groundwaters. Testing requirements and frequencies are shown on Table 7.19.

Wells should be monitored to identify any harmful effects on groundwaters. Sampling wells should be located within the irrigation site as well as near the site and on all sides to identify any changes or trends in water quality. Typical tests and frequencies are listed in Table 7.20.

TABLE 7.19 TESTING REQUIREMENTS

Area	Test	Frequency
Effluent and groundwater or seepage	BOD	two times per week
	Fecal coliform	weekly
	Total coliform	weekly
	Flow	continuous
	Nitrogen	weekly
	Phosphorus	weekly
	Suspended solids	two times per week
	pH	daily
	Total dissolved solids (TDS)	monthly
	Boron	monthly
	Chloride	monthly
Vegetation	— variable depending on crop —	
Soils	Conductivity	two times per month
	pH	two times per month
	Cation exchange capacity[6]	two times per month

TABLE 7.20 WELL MONITORING PROGRAM

Area	Test	Frequency
Wells	Salinity	
	Conductivity	Monthly
	Chloride	Quarterly
	TDS	Quarterly
	Chemical Buildup	
	Nitrate	Monthly
	Calcium	Semi-annually
	Magnesium	Semi-annually
	Toxicity (Heavy Metals)	
	Cadmium	Monthly
	Lead	Annually
	Zinc	Annually
	Mercury	Annually
	Molybdenum	Annually
	Selenium	Annually
	Organics	
	Trihalomethanes	Quarterly
	Pesticides (depends on local application)	Quarterly

7.81 Interpretation of Test Results and Follow-up Actions

Excessive levels and concentrations greater than desired for effluent BOD, fecal and total coliforms, nitrogen, phosphorus, and suspended solids are not a concern for crop-growing operations. The total dissolved solids (TDS), boron, chloride, and pH are important during long periods of land treatment, but not for times less than 2 to 3 weeks. Excessive nitrogen is a potential problem in spreading basins since nitrate in water supplies can be harmful to infants. If TDS, boron, or chloride levels increase and do not return to previous levels, a change in farming practices may be necessary.

Increased levels in any of the constituents in the groundwater are unacceptable. Most likely the only constituent that will increase is nitrate-nitrogen. If this occurs, then a nitrogen removal system (partial or complete) should be added to the treatment plant.

7.9 SAFETY

Safe operating procedures should be practiced in all undertakings. The operation of a sprinkler irrigation system has caused fatalities among operation personnel. Many of the fatalities have resulted from contact with electricity used either to power the pumping plant or to transmit electricity associated with the area being irrigated.

Moving of portable sprinkler lateral pipelines has been the worst offender. Raising a pipeline into the air to dislodge a small animal or debris and contacting overhead electrical transmission lines has resulted in severe electrical shock or death to the person holding the pipe.

A sprinkler throwing a stream of water into a power line has shorted the power to ground through the sprinkler system and resulted in severe electrical injuries to anyone touching the sprinkler system parts.

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[6] *Cation Exchange Capacity. The ability of a soil or other solid to exchange cations (positive ions such as calcium, Ca^{+2}) with a liquid.*

Always have the electric motor well bonded to a good ground with suitable-size conductors. Injuries have occurred from touching an ungrounded motor or pump frame having shorted electrical windings in electrically powered pumping plants.

Electrical shocks have occurred from faulty starting equipment and from working on energized circuits. Always pull the line disconnect switch; lock out and tag it when making repairs or checks on electrical equipment of any kind.

Look over each sprinkler system and mark the potential safety hazards, then avoid the hazards.

Surface spreading systems can be hazardous due to wet surfaces and muddy areas.

7.10 MAINTENANCE

Maintenance of land treatment systems requires keeping the wastewater distribution piping, valves and sprinklers in good working condition. Pump and valve maintenance is discussed in Chapter 15, "Maintenance," Vol. II. Storage reservoir maintenance is similar to pond maintenance outlined in Chapter 9, Vol. I.

7.11 REVIEW OF PLANS AND SPECIFICATIONS

Many operational and maintenance problems can be avoided by a careful review of the plans and specifications for a land treatment system. Be sure to look for the items listed in this section.

1. Ponding

   Ponding problems can be avoided if the proper site is selected and provided with proper drainage. Soils at the site must be suitable for percolation and for planned crops. Adequate drainage (no ponding) can be provided by leveling or sloping of the land surface so the water will flow evenly over all of the land. *DRAINAGE WELLS*[7] or *DRAIN TILE SYSTEMS*[8] may be necessary to remove excess water and prevent ponding.

2. Plastic pipe laterals

   Plastic pipe laterals installed above ground may break because of cold weather or deteriorate due to sunlight. Install plastic pipe laterals below ground.

3. Screens

   Install screens on the inlet side of irrigation pumps to prevent spray nozzles from becoming plugged.

4. Buffer area

   Be sure sufficient buffer area is provided around spray areas to prevent mist from drifting onto nearby homes and yards. If necessary, do not schedule spraying during days when the wind is blowing toward neighbors.

5. Odor

   If odors may be a problem, consider furrow or flood irrigation rather than spraying. Spraying can cause odor problems by releasing odors to the atmosphere.

6. Protection of pumps

   Excessive wear on pumps can result from sand in the water being pumped. If sand is a problem, improve pretreatment or install a sand trap ahead of the pumps. Remember to drain out of service pumps before freezing weather occurs in the fall or winter.

7. Alternate place to pump effluent

   An alternate location to pump or dispose of effluent is very important in case of system failure.

7.12 REFERENCES AND ADDITIONAL READING

7.120 References

1. Pound, C.E., et al., *COSTS OF WASTEWATER TREATMENT BY LAND APPLICATION*, Environmental Protection Agency, EPA-430/9-75-003, June 1975.
2. Pound, C.E., et al., *EVALUATION OF LAND APPLICATION SYSTEMS*, Environmental Protection Agency, EPA 430/9-74-015, September 1974.
3. Norum, Edward (editor), *WATER RESOURCE MANUAL*, available through The Irrigation Association, 1911 N. Ft. Myer Drive, Suite 1009, Arlington, VA 22090. Price $60.00.
4. Richard, L.A. (editor), *DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALINE SOILS*, Agricultural Handbook No. 60, U.S. Department of Agriculture, August 1969.

7.121 Additional Reading

1. *MANUAL OF WASTEWATER OPERATIONS*, Chapters 3 and 22, prepared by the Texas Water Utilities Association. Obtainable from Texas Water Utilities Association, 6521 Burnet Lane, Austin, Texas 78757. Price $19.09.
2. California Fertilizer Association, *WESTERN FERTILIZER HANDBOOK*, available through Customer Service, The Interstate Printers and Publishers, Inc., 19-27 North Jackson Street, Danville, Illinois, 61832. Price $10.95.
3. McKee, J.E. and Wolf, H.W., *WATER QUALITY CRITERIA*, Second Edition, report to California State Water Resources Control Board, SWRCB Publication 3A, Sacramento, California 1963. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB8 2188244. Price $40.00.
4. Pettygrove, G.S., and Asano, T, *IRRIGATION WITH RECLAIMED MUNICIPAL WASTEWATER — A GUIDANCE MANUAL*. Obtain from Lewis Publishers, Inc., 121 South Main Street, PO Drawer 519, Chelsea, Michigan 48118. Price $34.95.

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[7] *Drainage wells. Wells that can be pumped to lower the groundwater table and prevent ponding.*

[8] *Drain tile systems. A system of tile pipes buried under the crops that collect percolated waters and keep the groundwater table below the ground surface to prevent ponding.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 430.

7.8A What are the four monitoring areas for an irrigation system where crops are grown?

7.9A What is the major cause of accidents to operators while working with sprinkler irrigation systems?

7.10A What equipment needs to be maintained in a land treatment system?

7.11A List the items that should be examined when reviewing plans and specifications for a land disposal system.

END OF LESSON 2 OF 2 LESSONS
ON
WASTEWATER RECLAMATION

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 2 Lessons)

Chapter 7. WASTEWATER RECLAMATION

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

6. How does land treatment work?
7. What should be done with wastewater that seeps out of storage reservoirs and runs off from a land treatment system?
9. How long should the pumps be run while irrigating a plot of land?
10. What water quality indicators should be monitored to insure that a land disposal system does not adversely affect a groundwater supply?
11. How can safety hazards be avoided while operating a sprinkler irrigation system?

WORK THE OBJECTIVE TEST NEXT

SUGGESTED ANSWERS

Chapter 7. WASTEWATER RECLAMATION

Answers to questions on page 400.

7.0A Uses of reclaimed wastewater include:

1. Irrigation for crop or plant growth,
2. Indirect reuse by downstream users,
3. Direct reuse by industry,
4. Use as a fresh water barrier to prevent salt water intrusion by deep well injection,
5. Groundwater recharge by spreading basins, and
6. Reservoirs for recreation.

7.0B Oil that was not removed by previous pumping efforts will float on top of water supplied by deep well injection. The oil is then easier to pump to the surface from underground areas.

Answers to questions on page 410.

7.1A Coliforms and pathogenic bacteria can be killed by chlorination.

7.1B "Blend" water is sometimes mixed with plant effluent because this may be the best (most economical) means of achieving the water quality desired by the water users.

7.1C Probable causes of wastewater reclamation plant being unable to maintain a chlorine residual include:

1. Chlorinator not working properly, and
2. An increase in the chlorine demand.

Answers to questions on page 412.

7.2A

Possible causes of clogging	Possible cures for cause
1. Slimes	1. Chlorination or allow well to rest.
2. Carbon fines	2. Remove fines by passing the water through a sand/anthracite filter.

7.2B If reclaimed effluent was being used by industry and one of the water quality standards was not being met, *NOTIFY THE INDUSTRY IMMEDIATELY*.

7.3A Always work with another operator when working around storage reservoirs or blending tanks so help will be available and prevent you from drowning if you fall into the water.

END OF ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 418.

7.6A *EVAPOTRANSPIRATION.* The total water removed from an area by transpiration and by evaporation from soil, snow and water surfaces. *HYDROLOGIC CYCLE.* The processes involved in the transfer of moisture from the sea to the land and back to the sea again.

7.6B Land disposal of wastewater is accomplished by:

1. Irrigation,
2. Overland flow, and
3. Infiltration-percolation.

7.6C The major parts of land application systems include:

1. Preapplication treatment,
2. Transmission to the land site,
3. Storage,
4. Distribution over site,
5. Runoff recovery system (if needed), and
6. Crop systems.

7.6D

Known	**Unknown**
Length, ft = 2000 ft	Hydraulic Loading,
Width, ft = 1000 ft	1. MGD/acre
Flow, MGD = 1 MGD	2. Inches/day

1. Determine surface area in acres.

$$\text{Area, acres} = \frac{\text{Length, ft} \times \text{Width, ft}}{43{,}560 \text{ sq ft/acre}}$$

$$= \frac{2000 \text{ ft} \times 1000 \text{ ft}}{43{,}560 \text{ sq ft/acre}}$$

$$= 45.9 \text{ acres}$$

2. Determine hydraulic loading, MGD/acre.

$$\text{Loading, MGD/ac} = \frac{\text{Flow, MGD}}{\text{Area, acre}}$$

$$= \frac{1 \text{ MGD}}{45.9 \text{ acres}}$$

$$= 0.02 \text{ MGD/ac}$$

3. Determine hydraulic loading, inches/day

$$\text{Loading, in/day} = \frac{\text{Flow, MGD} \times 1{,}000{,}000/\text{M} \times 12 \text{ in/ft}}{\text{Length, ft} \times \text{Width, ft} \times 7.48 \text{ gal/cu ft}}$$

$$= \frac{1 \text{ M Gal/day} \times 1{,}000{,}000/\text{M} \times 12 \text{ in/ft}}{2000 \text{ ft} \times 1000 \text{ ft} \times 7.48 \text{ gal/cu ft}}$$

$$= 0.8 \text{ in/day}$$

Answers to questions on page 423.

7.7A The major items of equipment that should be inspected before starting a spray irrigation system include:

1. Electric motors,
2. Pumps,
3. Aluminum tubing, and
4. Sprinkler systems.

7.7B

Known	**Unknown**
Area, ac = 30 acres	Time to irrigate, hr
Soil type = Medium	
Root zone, ft = 2 ft deep	
Moisture = 50% retention	
Pump, GPM = 1200 GPM	

1. Determine inches of water to be applied.

   From Table 25.16
   Application, in = 1.69 inches

2. Determine time to irrigate 30 acres to apply one inch with a 1200 GPM pumping system capacity.

   From Figure 7.13
   Time to irrigate 1 inch = 11 hours

3. Determine total time to irrigate in hours.

$$\text{Time, hrs} = \text{Time (hr) to irrigate} \times \text{Amount to apply, in}$$

$$= 11 \text{ hour/inch} \times 1.69 \text{ inches}$$

$$= 18.6 \text{ hours}$$

Answers to questions on page 427.

7.7C The main objective of a land disposal system is to dispose of effluent without harming surface waters or creating nuisance conditions.

7.7D The three main areas of process control in a land disposal system are:

1. Storage reservoir,
2. Runoff and seepage water recycle systems, and
3. Impact of minerals in effluent on crop production in saline and alkali soils.

7.7E A minimum of four points in a storage reservoir should be sampled for DO.

7.7F The minimum DO requirements for a storage reservoir are a minimum DO of 0.4 mg/*L* for all samples and the average of all samples should be at least 0.8 mg/*L*.

7.7G Probable causes of ponding include:

1. Application rate is excessive;
2. If application rate is normal, drainage may be inadequate; and
3. A broken pipe in the distribution system.

Answers to questions on page 429.

7.8A The four monitoring areas for an irrigation system where crops are grown are:

1. Effluent,
2. Vegetation,
3. Soils, and
4. Groundwater.

7.9A The major cause of accidents to operators while working with sprinkler irrigation systems is contact with electricity used either to power the pumping plant or to transmit electricity associated with the area being irrigated.

7.10A Equipment requiring maintenance in a land treatment system includes distribution piping, pumps, valves and sprinklers.

7.11A Items to be examined when reviewing the plans and specifications for a land disposal system include:

1. Ponding,
2. Plastic pipe laterals,
3. Screens,
4. Buffer area, and
5. Protection of pumps.

END OF ANSWERS TO QUESTIONS IN LESSON 2

OBJECTIVE TEST

Chapter 7. WASTEWATER RECLAMATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each question.

1. Industrial cooling waters must be of a higher quality than water used for food processing.
   1. True
   2. False

2. One purpose of the aeration tank in a wastewater reclamation plant for a steel mill is for biological oxidation.
   1. True
   2. False

3. There are no safety hazards associated with the handling of portable sprinkler pipelines.
   1. True
   2. False

4. An industry may use reclaimed effluent directly for washing purposes or as influent to a specialized water treatment plant.
   1. True
   2. False

5. The method of irrigation depends on the type of crop being grown.
   1. True
   2. False

6. Which of the following constituents in reclaimed water could cause problems for the water user in a nuclear generating station?
   1. Ammonia
   2. Alkalinity
   3. Calcium
   4. Silica
   5. Sulfate

7. Reclaimed wastewater may be used for
   1. A freshwater barrier to prevent salt water intrusion.
   2. Cooling water by industry.
   3. Distilled water in a car battery.
   4. Irrigation of crops.
   5. Recreation lakes.

8. Problems that may develop during the injection of reclaimed wastewaters into deep wells include
   1. Groundwater contamination.
   2. Increased lowering of groundwater table.
   3. Salt water intrusion.
   4. Slime growths.
   5. Well clogging and loss of recharge capacity.

9. Safety hazards around a wastewater reclamation facility include
   1. Drowning.
   2. Electrical shock.
   3. Pathogenic bacteria.
   4. Slippery surfaces.
   5. Toxic gases.

10. Water quality criteria for wastewater reclaimed for recreational uses include
    1. Alkalinity.
    2. Coliform group bacteria.
    3. Floatable solids.
    4. Hardness.
    5. Nutrients.

11. What would you do if the effluent from a wastewater reclamation facility did not meet the water quality standards of the water users?
    1. Divert the flows to emergency storage if available
    2. Install better monitoring equipment
    3. Locate the cause of the problem and attempt to correct the problem
    4. Notify the user immediately
    5. Try to have the standards adjusted to more reasonable values

12. Land disposal of wastewater may be done by which of the following methods?
    1. Dilution
    2. Discharge to a river
    3. Infiltration-percolation
    4. Irrigation
    5. Overland flow

13. Which of the following methods of wastewater disposal are best suited for crop production?
    1. Deep-well injection
    2. Groundwater recharge
    3. Infiltration-percolation
    4. Irrigation
    5. Overland flow

14. Which of the following chemical properties are used in the classification of irrigation waters?
    1. BOD
    2. Boron
    3. Chloride
    4. pH
    5. Total dissolved solids

15. How can an operator determine if too much water is being applied to a land disposal irrigation system?
    1. By observing growth of multiple crops
    2. By observing ponding
    3. By observing runoff
    4. By observing that the storage reservoir is empty
    5. By observing weeds

16. Probable causes of ponding in a land disposal system include
    1. Broken pipe in distribution system.
    2. Bulking sludges.
    3. Clogged sprinkler nozzles.
    4. Excessive application rates.
    5. Inadequate drainage.

17. What could be possible causes of a dead irrigated crop?
    1. Inadequate drainage has flooded root zone of crop
    2. Not enough water has been applied
    3. Too much insecticide or weed killer applied
    4. Too much water has been applied
    5. Wastewater contains an excessive amount of toxic elements

18. Safety hazards when operating a sprinkler irrigation system include
    1. A sprinkler throwing a stream of water into a power line.
    2. Drowning.
    3. Faulty electrical pump motor starting equipment.
    4. Portable sprinkler pipelines coming in contact with overhead electrical transmission lines.
    5. Ungrounded motor or pump frames.

19. Possible solutions to deterioration of lateral aluminum distribution piping include
    1. Adding corrosion inhibiting chemicals to water.
    2. Adjusting the pH of the water.
    3. Burying the pipe.
    4. Draining lines except when in use.
    5. Installing cathodic or anodic protection.

20. Why might the effluent from your wastewater treatment plant be reused directly by someone?
    1. Cost of obtaining groundwater is prohibitive.
    2. Cost of purchasing treated water is too high
    3. Sufficient municipal water is not available
    4. Surface waters are not available
    5. To discourage community growth

21. Which of the following tests are performed on the soils in an effluent disposal on land program?
    1. BOD
    2. Cation exchange capacity
    3. Conductivity
    4. DO
    5. pH

22. Which one(s) of the following items are limitations of land treatment systems?
    1. Energy requirements for land treatment systems are high
    2. Maintenance requirements for land treatment systems are both complex and costly
    3. Rain can soak the soil so no wastewater can be treated
    4. Salts can build up in the soil to levels toxic to plants
    5. Suspended solids can form a mat that will seal the land surface

23. Problems caused by the buildup of salts in soils can be corrected by
    1. Adding an acid to the soil, such as nitric acid.
    2. Adding a base to the soil, such as sodium hydroxide.
    3. Leaching out the salts by applying fresh water.
    4. Removing the salts from the effluent by a distillation process.
    5. Ripping up the field and turning it over to a depth of 4 or 5 feet.

24. The most important observations in a land treatment system where crops are grown and surface runoff is not allowed are observing
    1. Exfiltration.
    2. Percolation.
    3. Ponding.
    4. Salt buildup.
    5. Surface runoff.

END OF OBJECTIVE TEST

CHAPTER 8

INSTRUMENTATION

by

George Ohara

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OBJECTIVES

Chapter 8. INSTRUMENTATION

After completion of Chapter 8 you should be able to do the following:

1. Describe the need for instrumentation and controls,
2. Indicate the variables or values measured by instruments and how they are measured,
3. Identify a controller and describe its purpose,
4. Identify recorders — indicators and describe their purpose,
5. Read instruments and controls and make proper adjustments in operation of treatment plant,
6. Determine location and cause of instrument and control failures and take corrective action, and
7. Maintain instruments and controls.

ALWAYS REMEMBER: If you don't know what you are doing, *HANDS OFF!*

GLOSSARY

Chapter 8. INSTRUMENTATION

HYDROSTATIC SYSTEM
HYDROSTATIC SYSTEM

In a hydrostatic sludge removal system, the surface of the water in the clarifier is higher than the surface of the water in the sludge well or hopper. This difference in pressure head forces sludge from the bottom of the clarifier to flow through pipes to the sludge well or hopper.

OFFSET (or DROOP)
OFFSET

The difference between the actual value and the desired value (or set point) characteristic of proportional controllers that do not incorporate reset action.

PROCESS VARIABLE
PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled.

SET POINT
SET POINT

The position at which the control or controller is set. This is the same as the desired value of the process variable.

SOFTWARE PROGRAMS
SOFTWARE PROGRAMS

Computer programs designed and written to monitor and control wastewater treatment processes or other processes.

TIME LAG
TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level.

CHAPTER 8. INSTRUMENTATION

(Lesson 1 of 4 Lessons)

8.0 NEED FOR INSTRUMENTATION AND CONTROLS

With today's tougher discharge and monitoring requirements, more and more wastewater treatment plants are being designed and constructed with sophisticated instrumentation and control systems to help operators do their job. Consequently, this chapter on instrumentation and controls is dedicated to familiarizing the operator with the role instruments and controls play in the operation of a wastewater treatment plant. We will define instruments and controls, what they do, how they do their job, how they are related to plant operations, and the care they should receive. This chapter will not attempt to cover the theory of instruments and controls, their design, construction, and repair. These matters are best left to qualified instrument personnel that have the necessary training, experience, and equipment to do the job. So let's get started!

8.00 What are Instruments and Controls?

Simply stated *AN INSTRUMENT IS NOTHING MORE THAN A MEASURING DEVICE.* Let's look at a few samples.

One of the simplest and most common examples of a measuring device is the rule or tape measure. Rulers are used to measure linear (lengthwise) distances. The distances may be measured in the terms of inches, feet, fractions, decimals or in metric units. Depending upon the job we have to do, we may choose to use a 6-inch pocket scale or a 100-foot tape measure as a measuring device (Fig. 8.1).

Another common and familiar instrument is the clock or wrist watch which we use to measure time. We may measure time in units of seconds, minutes, hours or days, depending upon our needs. The clock may be mounted on a building for all to see or it may be a wrist watch for personal use (Fig. 8.2).

Another common instrument is the bathroom scale that we use to measure our weight. Scales may measure in terms of pounds and ounces, pounds and decimals of a pound, or in grams in the metric system. There are many different types of scales used to measure weight. A postage scale (Fig. 8.3) used to weigh letters cannot be used to weigh groceries nor can the scale used to weigh chlorine containers be used to weigh the small amounts of solid residues measured in the lab.

An instrument is selected on the basis of a particular job it has to do.

In review of what has been discussed, we may simply state that instruments are measuring devices. They may directly or indirectly measure many quantities whose values or changes in values are both necessary and useful information for operating a treatment plant.

Next, let us describe controls and their uses. Simply stated *CONTROLS ARE DEVICES OR A SERIES OF DEVICES THAT EFFECT SOME CHANGE DUE TO SOME OTHER CHANGE IN CONDITIONS.*

One of the most sophisticated and common control systems is the human body. An example of this concept is a person opening a door. We can designate the eyes as a sensing instrument to determine (measure) whether the door is closed or open and the nervous system as a transmission system (message sending-receiving device). The brain is the control logic and the arms-hands are the control output. We can simulate a control system as follows:

1. The eyes measure the door as closed.
2. The eyes transmit a signal to the brain whose logic has been established for "door open."
3. The brain, receiving the signal coded as "closed door," institutes an action to open the door.
4. The brain transmits a coded signal to the arm and hand calling for turning of the door knob and opening the door.
5. The eyes then measure the door as opened and transmit a signal coded as "satisfactory" to the brain ending this particular control sequence.

An example of a simple household control system is the thermostatically controlled heating system in your house. In this case the thermostat (Fig. 8.4), which is a temperature measuring and sensing device, sends an electrical signal to the heater causing it to fire up whenever the room temperature drops below a pre-determined level. After the rooms have warmed up to the pre-determined level, the thermostat stops sending an electrical message to the heater (Fig. 8.5) and the heater will shut down automatically. The control process may be analyzed as follows:

1. The thermostat senses the temperature has dropped below 70°F (21°C) and trips an electrical relay.
2. The relay transmits an electrical message to the heater's fuel regulation system where another device (solenoid) turns the fuel source to the "ON" position; this causes the heater to "light up" and produce heat.
3. After a period of heating, the room warms up to 70°F (21°C) or slightly more and causes the thermostat to cease sending an electrical signal to the heater's fuel regulation system. This, in turn, causes the heater to go "OFF" and prevents overheating of the room.
4. The whole sequence will repeat itself when the room temperature again falls below 70°F (21°C).

So far we have discussed a sophisticated biological control system, the human body, and a simple electrical control system. Next let us examine a simple hydro-mechanical control system that is familiar to all of us.

The toilet bowl flush tank uses a simple hydraulic and mechanical control system. When the bowl is flushed and the tank is empty, the tank starts to fill up automatically. Also, the tank

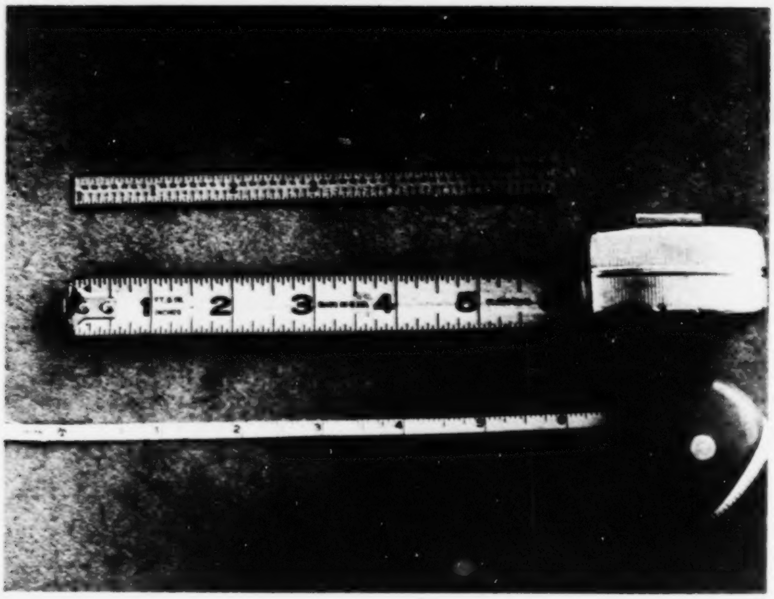


Fig. 8.1 Rulers and tape measures are common devices used to measure length

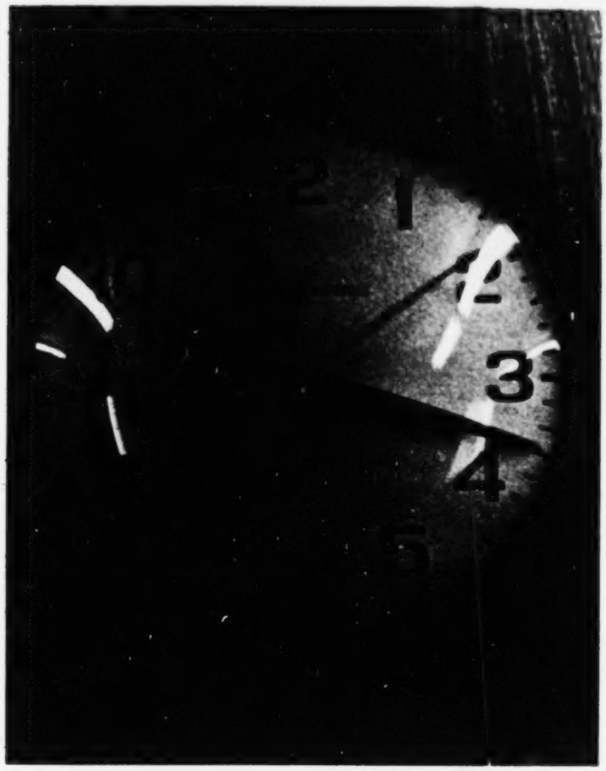


Fig. 8.2 Clocks are instruments that measure time

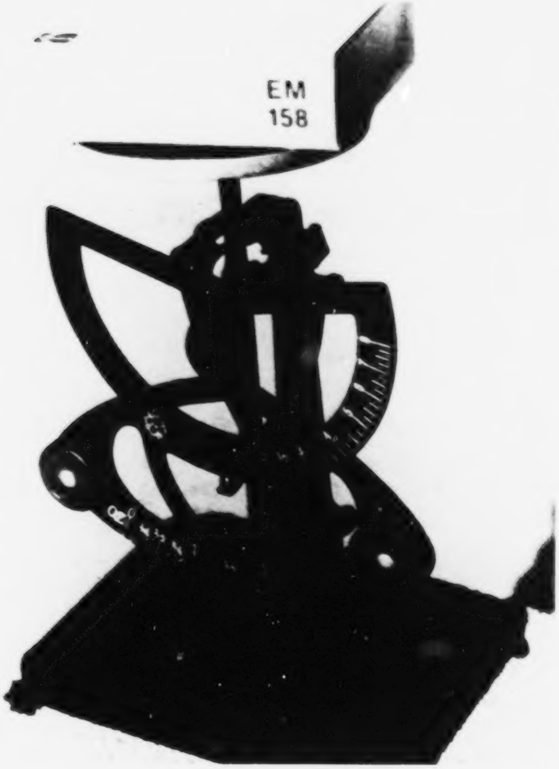


Fig. 8.3 A postage scale measures weight

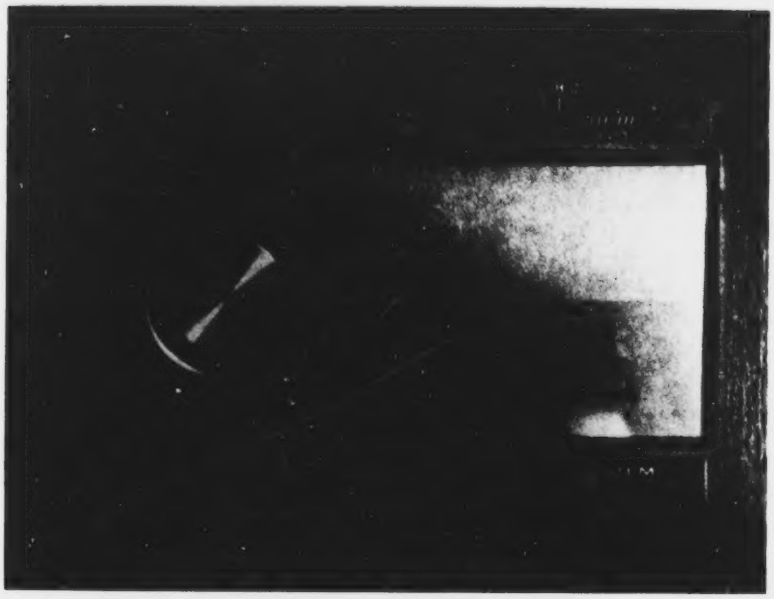


Fig. 8.4 A thermostat senses and measures heat

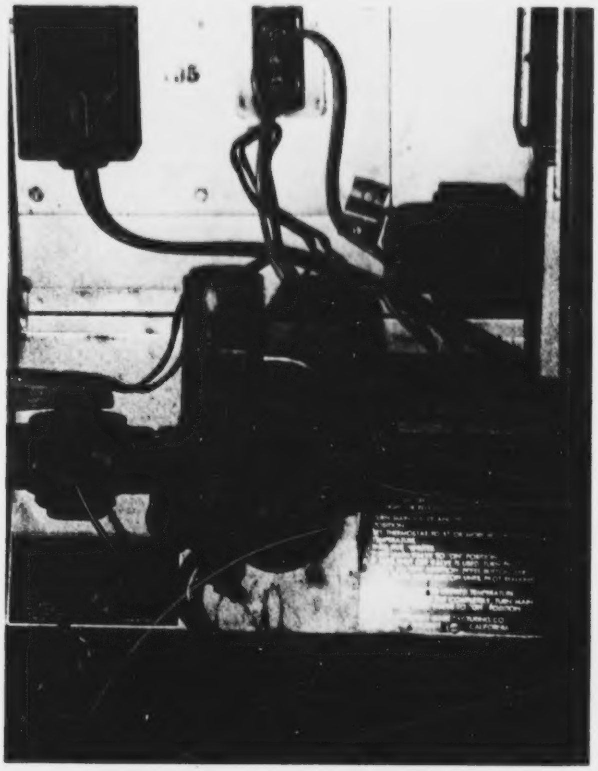


Fig. 8.5 A gas burner heater system is controlled by a thermostat

shuts off automatically when it is full. This control system may be analyzed as follows:

1. The bowl is flushed and the water level drops in the flush tank.
2. This causes the float to drop (Fig. 8.6). The dropping of the float mechanically opens a hydraulic valve which releases water into the flush tank.
3. As water begins to rise in the tank, the float also rises. This in turn controls the amount of water entering the flush tank. Thus, the higher the float level, the lower the rate of water coming into the tank.
4. Finally, when the water level in the flush tank reaches its pre-set level, the float will also have risen to its maximum height. When the float reaches its maximum height (Fig. 4.7), it will automatically shut off the valve feeding water into the flush tank. This is accomplished through a set of mechanical levers.
5. The sequence will repeat itself whenever the toilet is flushed again.

The example above illustrates a hydro-mechanical control system using a simple float as the water-level measuring device and control system to either turn the water "ON" or "OFF" into the flush tank.

Therefore, an instrument may be defined as a measuring device; a control system is a device or series of devices that cause changes to occur. In the next section, we will examine why we need instruments and controls to operate a treatment plant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.0A Why are treatment plants being designed and constructed with sophisticated instrument-control systems?

8.0B What is an instrument?

8.0C What is a control?

8.01 Why Use Instruments and Controls?

So far we have discussed simple instrument and control systems; now let us examine why they are necessary and useful in operating a treatment plant. Since instruments basically measure values, let us examine why we need to use instruments in place of or to assist the opeator's sense of sight, hearing, touch, and smell. When we talk about measuring, we are taking into consideration the following related factors:

1. Accuracy of the measurement,
2. Repeatability of the measurement,
3. Sensitivity of the measurement, and
4. Permanence of the measurement.

8.010 Accuracy

Let us first examine the need for accuracy of measurement. In some instances it may be adequate to "eyeball" a linear measurement. An example of this would be roughly pacing off the width of a sand sludge drying bed. No great degree of accuracy is required or implied by this method. However, in another situation where we were installing expensive piping between pieces of machinery, we would want to increase the degree of accuracy by using a tape measure instead of pacing off the distance. Another situation requiring still greater accuracy would be measuring the diameter of a replacement pump shaft. Here a micrometer would be used for measuring the diameter of the shaft to the nearest thousandth of an inch (Fig. 8.8). In the last two examples, an operator's eyeball calibration is inadequate for the accuracy needed and specific instruments must be used.

In another example, an operator would be able to tell the passing of a day's time, let's say from sunset to sunset, and that would be accurate enough to mark the days off a calendar. However, if the operator wanted to operate the primary sludge pumps ten minutes each hour, a watch would be needed since the degree of accuracy required is greater than the ability to "guesstimate" the passing of time (Figs. 8.9 and 8.10).

So, we may conclude that depending upon the degree of measurement accuracy required, different types of instruments are needed to assist the operator perform different tasks. The accuracy of an instrument depends on the preciseness or exactness of the measurements or how close the measurement is to the true value.

8.011 Repeatability

For our use, repeatability may be defined as the ability to measure something again and obtain the same answer that resulted previously.

In our very first accuracy measurement example of pacing off the width of a sludge drying bed, our repeatability would probably not be too consistent. However, since the information would not be sought day after day and would not change, it would not be too important. However, in the situation where we were using a micrometer to measure the diameter of a pump shaft, repeatability would be very critical. We could not tolerate even a small discrepancy in repeatability.

Therefore, we may summarize that the repeatability of instruments is unquestionably superior to that of human sense measurements and that in many treatment plant operations using flow, temperature, pressure and other process variables, repeatability is absolutely essential for good operations.

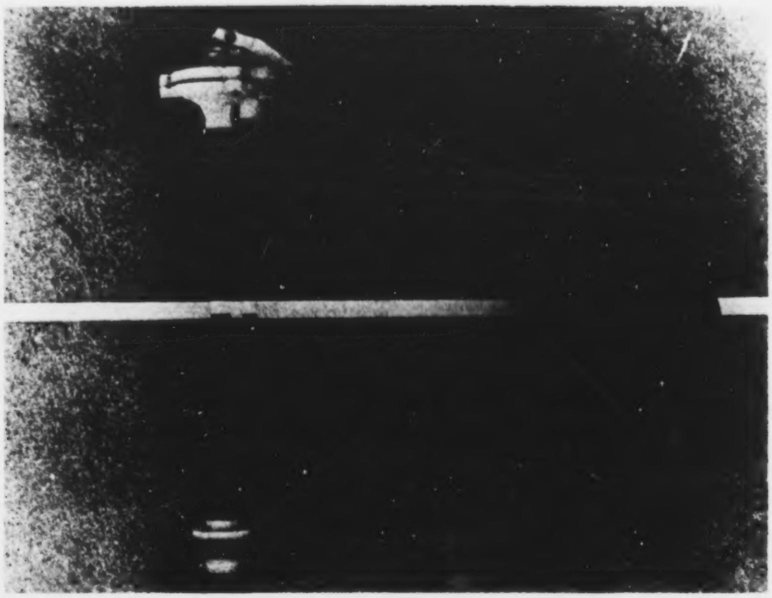


Fig. 8.6 Toilet bowl float in down position. Water will flow into toilet

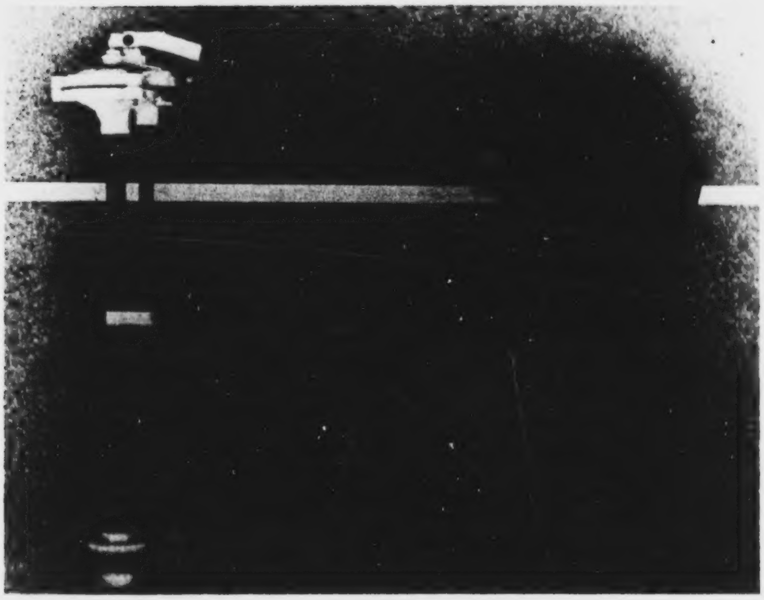


Fig. 8.7 Toilet bowl float in up position. Water will be shut off from flowing into toilet

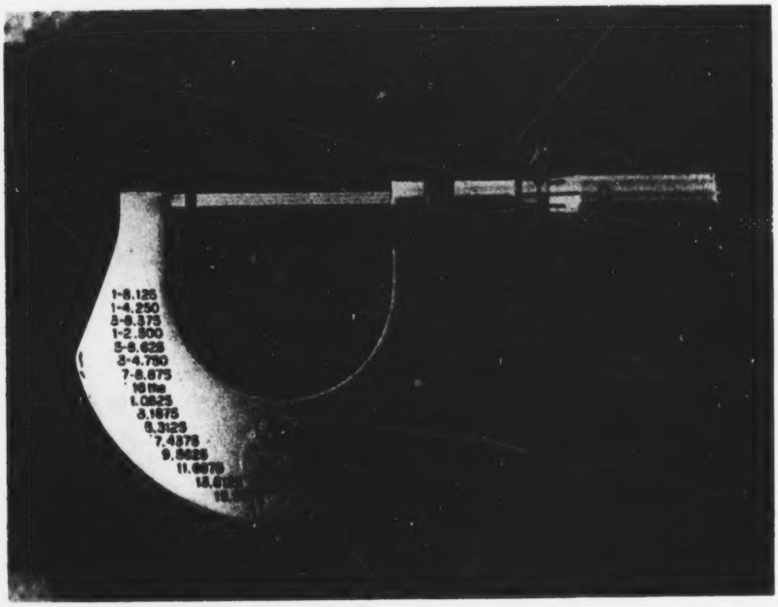

1-8.125
1-4.250
3-8.375
1-2.500
5-8.625
3-4.750
7-8.875
16ths
1.0625
3.1875
5.3125
7.4375
9.5625
11.6875

Fig. 8.8 A micrometer is used for close tolerance measurements

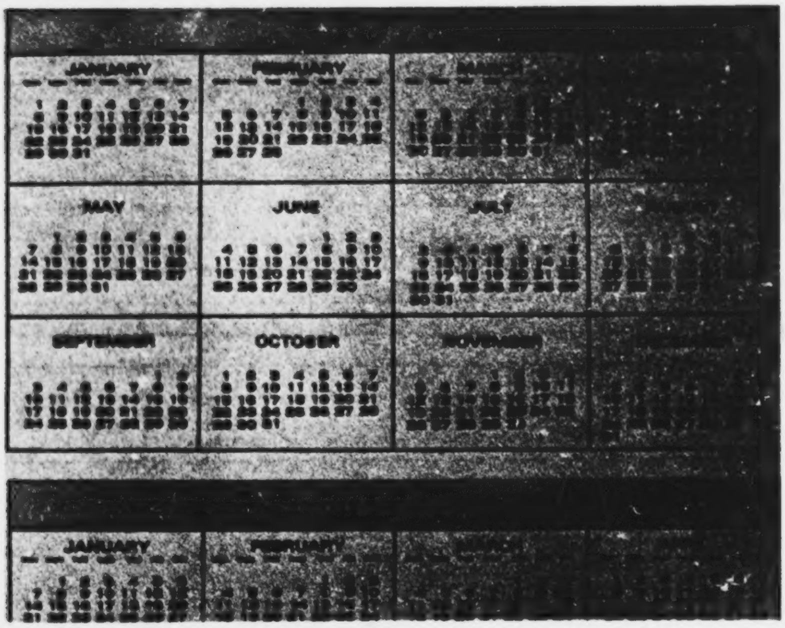

JANUARY
FEBRUARY
MAY
JUNE
JULY
SEPTEMBER
OCTOBER
JANUARY
FEBRUARY

Fig. 8.9 A calendar is used to measure long lengths of time

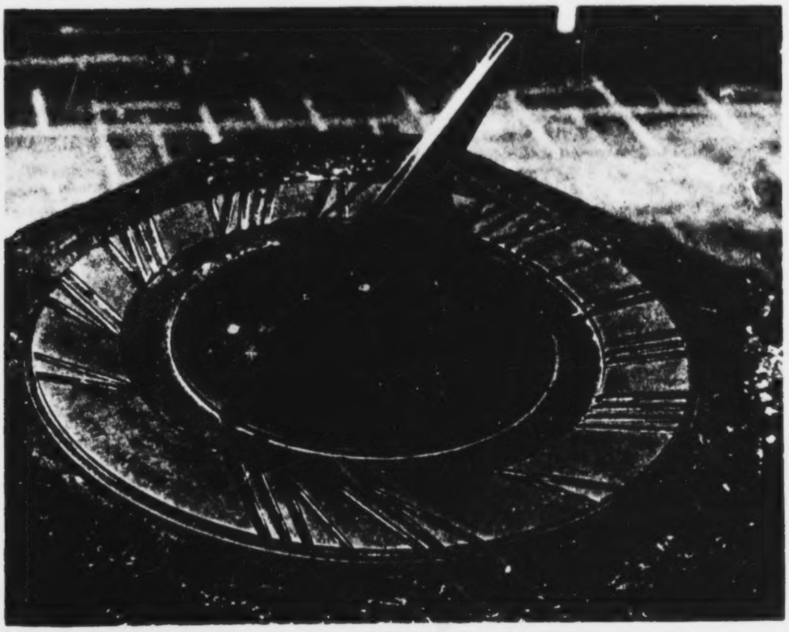


Fig. 8.10 A sundial is used to measure the approximate time of day. Sundials cannot measure time precisely.

8.012 Sensitivity

Sensitivity, for our use, may be defined as the ability to measure the smallest or largest value necessary.

As an example, the tape measurement would not be sensitive enough to measure to the nearest one thousandth of an inch. In another example, if we wanted to measure the gas pressure in an anaerobic sludge digester, we would want a pressure gage calibrated in inches or centimeters of water because 9 inches of water is only 0.32 psi. Therefore, a pressure gage calibrated in five-pounds-per-square-inch (5 psi or 0.4 kg/sq cm) increments would be too insensitive for our needs. In yet another example, a laboratory scale or balance (Fig. 8.11), calibrated in hundredths of a gram would be more sensitive than necessary and would not have the capacity to measure the weight of a chlorine cylinder in pounds. Therefore, the operator needs instruments that are properly sensitive to measure the smallest or largest unit (length, weight, time) increments necessary.

8.013 Permanence

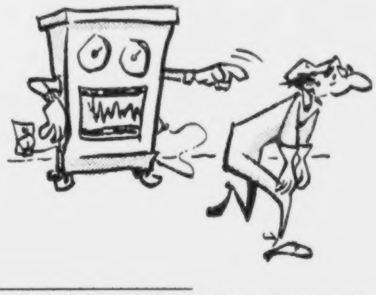
For the purposes of our use, permanence will be defined as maintaining accuracy, sensitivity, and repeatability over a long period of time. That is to say, a ruler or tape measure constructed out of paper would have little permanence. Conversely, a ruler constructed out of Invar metal would have very high permanence since it would be dimensionally stable.

In summary, we might say that good instruments exhibit a high degree of permanence, which is necessary for precise process control.

To this point we have discussed the ability of instruments to behave in an accurate, sensitive, repeatable and permanent manner in measuring numerous *PROCESS VARIABLES*[1] necessary for plant operations.

Instruments also measure variables which cannot be directly measured otherwise, for instance electricity. Human senses, for all practical purposes are incapable of measuring voltage and amperage (Fig. 8.12). Instruments also measure variables that would be unsafe to measure otherwise, such as extreme heat. Instruments that record also remove much of the drudgery associated with constant and repeated data taking. With the proper instruments, operators can measure chemical variables such as dissolved oxygen levels, pH (Fig. 8.13), chlorine residuals, and certain specific ions which could not otherwise be easily and/or quickly determined. Also, valuable time is saved by not having operators do jobs that could be done by instruments.

Therefore, we need and use instruments to accurately and quickly measure physical and chemical process variables that influence and/or control treatment plant processes. Human senses and "gut feelings" are no longer adequate to control a modern treatment plant.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.0D Why do we need to use instruments in place of or to assist the operator's sense of sight, hearing, touch, and smell?

8.0E What is meant by the sensitivity of a measurement?

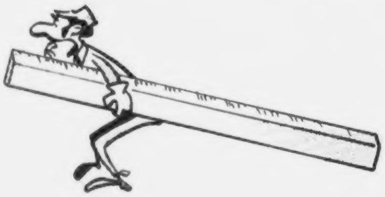
8.0F What is the difference between an instrument's accuracy and repeatability?

8.1 WHAT DO INSTRUMENTS MEASURE?

Thus far we have learned that instruments are some sort of measuring device. Also, that they are needed and used because they provide a more accurate, consistent, sensitive, and permanent means of monitoring (measuring) treatment processes than we can achieve by seeing, hearing, touching, or smelling.

Next we will discuss which values or variables are measured by instruments commonly used in wastewater treatment plants. We will define the meaning of the following measurements:

1. Temperature,
2. Pressure,
3. Flow,
4. Level,
5. Density,
6. Velocity, and
7. Analytical measurements (physical, chemical, or biological).



8.10 Temperature

Temperature may be defined as the degree of "hotness" or "coldness" of a substance from a given reference temperature. High temperatures are associated with a high level of molecular activity in a substance, and conversely, cold temperatures are associated with a low level of molecular activity. A good example of this would be water which, if heated enough, would turn into steam; if cooled enough, it would turn into ice.

Therefore, a thermometer (Fig. 8.14) or some other temperature-measuring device is used to measure the degree of hotness or coldness. With this information, we were able to control heat-sensitive processes within their optimum ranges (anaerobic sludge digestion) or be warned if safe temperature levels are exceeded (steam boiler).

8.11 Pressure

Pressure may be defined as a stress (push) uniformly exerted in all directions. For example, gas inside of a balloon exerts pressure uniformly to all parts of the balloon. A manometer (Fig. 8.15) or some other pressure measuring instru-

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[1] *Process Variable. A physical or chemical quantity which is usually measured and controlled.*

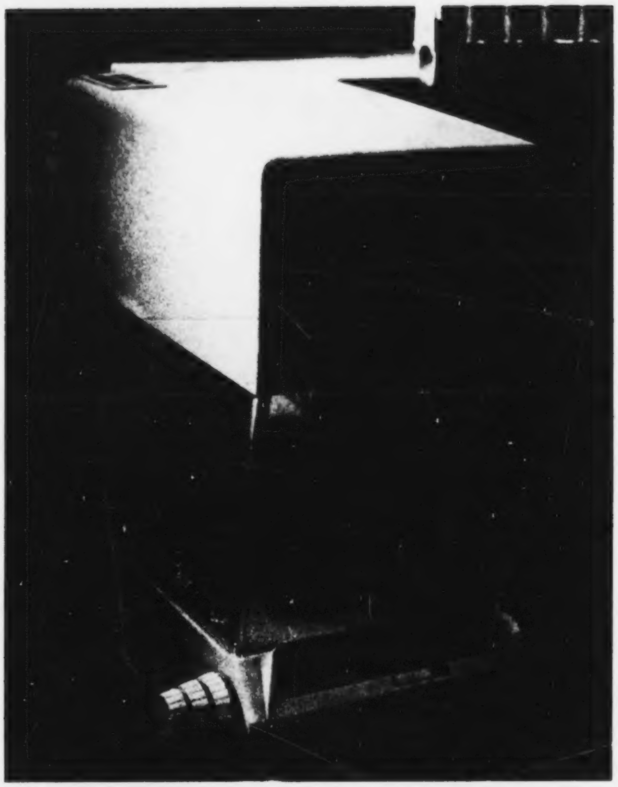

Fig. 8.11 A laboratory scale or balance is used to accurately measure small amounts of weights. Heavy quantities cannot be measured by lab scales.

Fig. 8.12 A wattmeter is used to measure electrical energy. Human senses cannot measure electrical quantities.

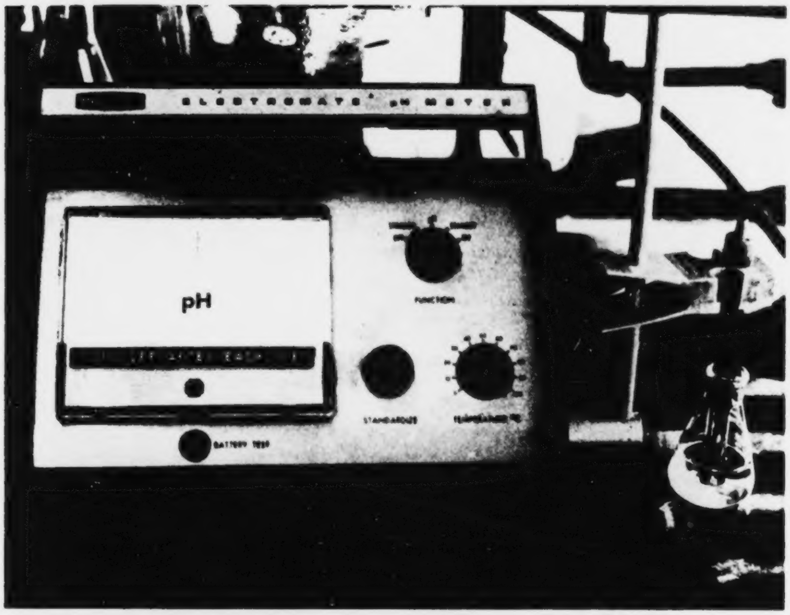

Fig. 8.13 A laboratory pH meter is used to measure a chemical quality of a liquid.

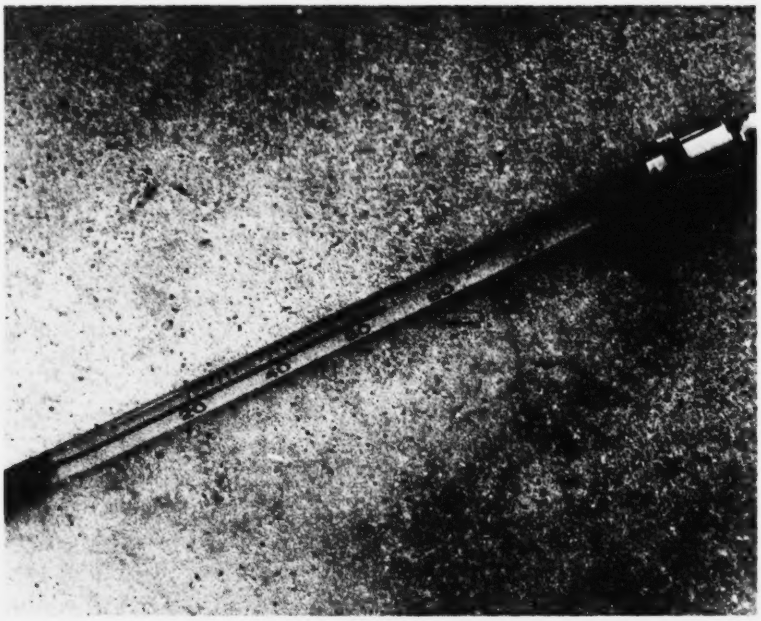

Fig. 8.14 A liquid-filled thermometer is used to measure temperature.

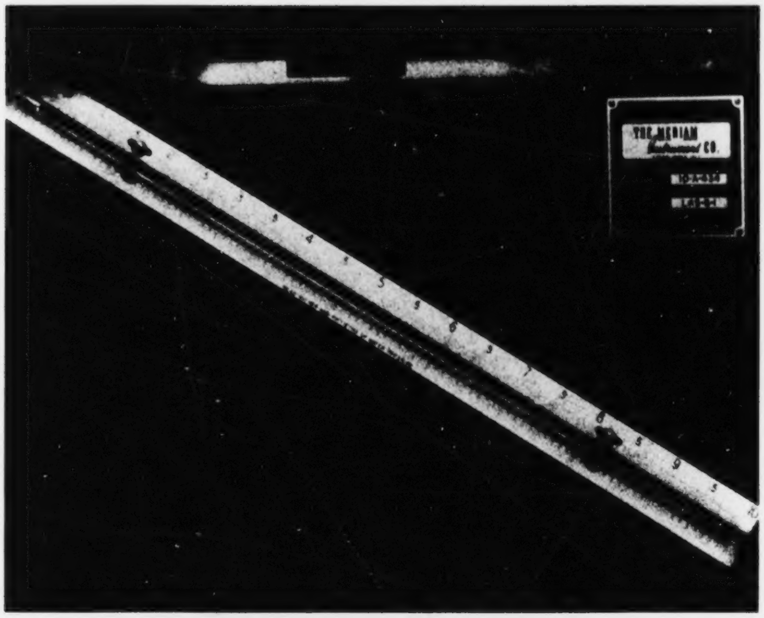
THE MERIAM
Instrument CO.

Fig. 8.15 An inclined manometer is used to measure relatively low pressures.

instrument is commonly used to measure the amount of pressure. Therefore, we are able to measure air pressure in order to limit the air pressure inside an air tank so that safe limits are not exceeded. Also, the suction and discharge pressures of a pump allow us to determine the total dynamic head (TDH) on a pump.

8.12 Flow

Flow may be defined in two ways, rate of flow and total flow or volume. Rate of flow may be defined as the volume of material passing a given point at any given *INSTANT OR TIME PERIOD.* Total flow may be defined as the amount or volume of flow passing a given point *WITHIN A SPECIFIC TIME PERIOD.*

For example, the return activated sludge (RAS) "flow rate" may be 200 GPM and the "total flow volume" would be 0.288 million gallons during one day.

$$\begin{aligned}\text{Flow volume, MG} &= \text{Flow rate, gal/min} \times \text{Time, day} \times 1440\ \text{min/day} \times \frac{1\ \text{Million}}{1{,}000{,}000}\\ &= 200\ \text{gal/min} \times 1\ \text{day} \times 1440\ \text{min/day} \times \frac{1\ \text{Million}}{1{,}000{,}000}\\ &= 0.288\ \text{MGal}\end{aligned}$$

8.13 Level

Level may be defined as a height measurement. Liquid surface levels can be measured directly by a floating ball or a measuring (dip) stick. For example, the amount of diesel fuel in a tank can be determined from the level of fuel. Sight tubes are used to measure liquid levels directly in a tank (Fig. 26.16). Levels also can be measured by indirect means such as electrical probes or by ultrasonic sound waves which bounce back like radar and induce a signal. Hydrostatic pressure in psi can be converted to a level or head by using the conversion factor 2.31 feet = 1 psi.

8.14 Density

Density may be defined as the weight of a material per unit volume. For example, the density of water is 62.4 lbs/cu ft. Liquid density may be measured by a hydrometer such as the type used to measure the amount of anti-freeze in a radiator. Primary sludge density may be measured by radioactive sensing cells.

8.15 Velocity (Speed)

Velocity may be defined as the length of travel in a given unit of time or: velocity = distance/time. An automobile speedometer (Fig. 8.17) measures velocity in terms of miles per hour. Another velocity or speed measurement is the RPM (revolutions per minute) made by an engine or pump (Fig. 8.18).

8.16 Analytical Measurements

Instruments also may be used to make analytical measurements. Chemical analytical or laboratory measurements are made for pH, dissolved oxygen, electrical conductivity, chlorine concentrations, and others. Physical measurements include turbidity and temperature while examples of a biological measurement are the tests to indicate the concentrations of coliform group bacteria or algae. Many laboratory measurements involve instruments using some sort of specialized probe and meter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.1A Why are instruments used instead of our human senses of seeing, hearing, touching, and smelling?

8.1B What do instruments measure?

8.1C How can flow be defined?

8.2 UNITS OF MEASUREMENT

Now that we understand what variables instruments measure, let us examine the common units of expression for these measurements.

1. *TEMPERATURE*

Fahrenheit: (English)	A unit of expression for temperature is the Fahrenheit scale, where the freezing of water is set at 32°F, and boiling of water is set at 212°F, covering a range of 180°F between the two points.
Celsius or Centigrade: (Metric)	Another common unit of temperature expression is the Celsius or Centigrade scale, which is commonly used in laboratory measurements and the metric system. The freezing of water is set at 0°C and boiling of water is set at 100°C, covering a range of 100°C between the two points.
Kelvin (Metric) & Rankine (English):	There are two other less commonly used temperature scales which incorporate the value of "Absolute Zero" where, theoretically, no molecular motion exists. The Kelvin scale sets the freezing point of water at +273°K and the boiling point at +373°K, giving a spread of 100° just like the Celsius scale. The Rankine scale sets the freezing point of water at +491.7°R and the boiling point at +671.7°R, giving a 180° spread between the points just like the Fahrenheit scale.

2. *PRESSURE*

Pounds per Square Inch:	The most common expression for pressure is pounds per square inch (psi). This means that each square inch of surface area is subjected to that many pounds of force. 1 psi = 0.070 kg/sq cm = 6895 Pascal = 6.9 kPa
Pounds per Square Foot:	Another pressure expression is given in pounds per square foot (psf). This means each square foot of surface area is subjected to that many pounds of force. 1 psf = 4.882 kg/sq m = 993 kPa

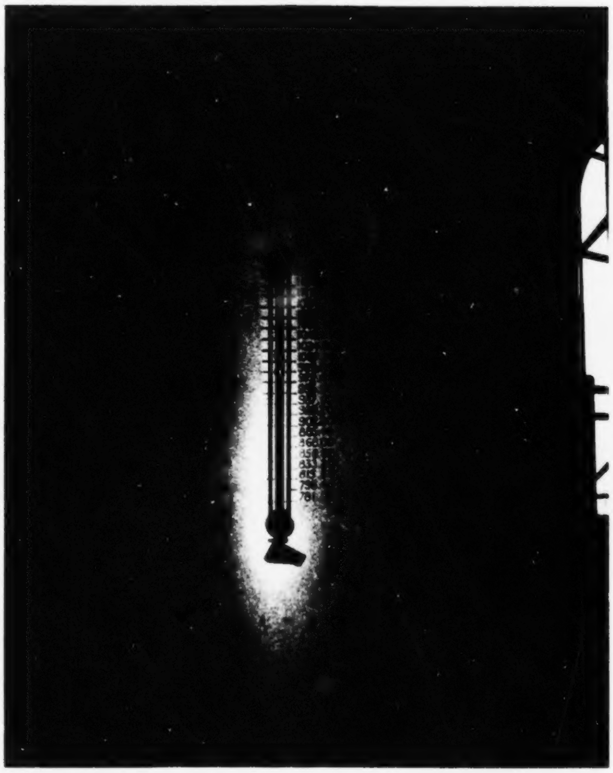

Fig. 8.16 Sight tubes are used to measure liquid levels directly in a tank.

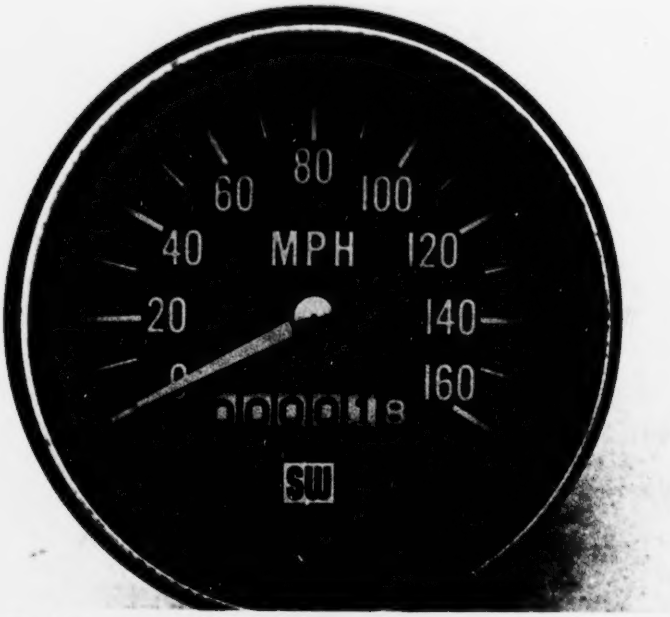
0
20
40
60
80
100
120
140
160
MPH
SW

Fig. 4.17 A speedometer is used to measure linear velocity.

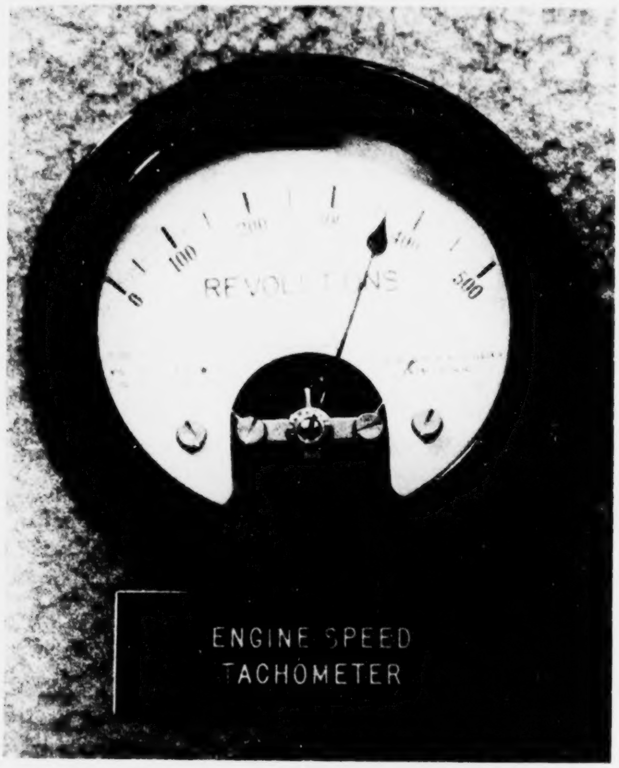
0
100
200
400
500
REVOLUTIONS
ENGINE SPEED
TACHOMETER

Fig. 8.18 A tachometer is used to measure rotational velocity.

Inches or Feet of Head: Pressure may also be expressed in terms of inches of water, feet of water, or inches of mercury (Hg). Each of these expressions is related to the pressure that would be required to support a column of given liquid sometimes called "Head." Mathematically stated, since one cubic foot of fresh water weighs 62.4 pounds and there are 144 square inches per square foot, a one square inch column of water one foot or 12 inches high exerts a pressure of 0.433 lbs/sq in. For example, when the manometer connected to the dome of an anaerobic sludge digester reads 9 inches (23 cm) of water (H_2O), what the manometer is telling us is that the gas pressure inside the digester is exerting a force equivalent to that required to support a column of water (head) 9 inches (23 cm) high.

$$
\begin{aligned}
\text{Pressure, lbs/sq in} &= \frac{\text{Weight, lbs}}{\text{Area, sq in}} \\
&= \frac{\text{Volume, cu ft} \times \text{Density, lbs/cu ft}}{\text{Area, sq in}} \\
&= \frac{\text{Area, sq in} \times \text{Height, in} \times \text{Density, lbs/cu ft}}{\text{Area, sq in} \times 1728\ \text{cu in/cu ft}} \\
&= \frac{1\ \text{sq in} \times 12\ \text{in} \times 62.4\ \text{lbs/cu ft}}{1\ \text{sq in} \times 1728\ \text{cu in/cu ft}} \\
&= \frac{0.433\ \text{lbs}}{1\ \text{sq in}} \\
&= 0.433\ \text{lbs/sq in}
\end{aligned}
$$

Therefore, 0.433 psi = 1 ft head = 0.3 m
or 1 psi = 2.31 ft head = 0.7 m

Gage and Absolute Pressure: Pressure also is expressed as gage pressure or absolute pressure (Fig. 8.19). Gage pressure does not take into consideration the weight of the atmosphere above the earth; one atmosphere = 14.7 psi or 29.97 inches of mercury at sea level. Therefore, in converting to absolute pressure from gage pressure you must add barometric pressure (14.7 psi) to the gage pressure reading.

$$\text{Gage Pressure, psi} + \text{Barometric Pressure, psi} = \text{Absolute Pressure, psi}$$

For practical purposes, operators commonly use gage pressure because they want to know the *DIFFERENCES* in water pressure. Usually atmospheric (barometric) pressure does not influence work done by operators. Absolute pressure is used when working with gases and calculating changes resulting from changes in the pressure, temperature, and/or volume of a gas.

Vacuum Pressure: So far we have been discussing positive pressures. Whenever a pressure falls below atmospheric pressure, a negative pressure is exerted which is called a vacuum. Consequently, when an open-tube manometer on a vacuum filter or vacuum receiver reads 20 inches (51 cm) of mercury (Hg), this is equivalent to a negative or minus gage pressure of 9.76 lbs/sq in (0.69 kg/sq cm). Mercury has a density 13.55 times heavier than water.

$$
\begin{aligned}
\text{Pressure, lbs/sq in} &= \frac{\text{Density, lbs/cu ft} \times \text{Head, ft}}{144\ \text{sq in/sq ft}} \\
&= \frac{13.55 \times 62.4\ \text{lbs/cu ft} \times 20\ \text{in}}{144\ \text{sq in/sq ft} \times 12\ \text{in/ft}} \\
&= 9.79\ \text{lbs/sq in}\ (0.69\ \text{kg/sq cm})
\end{aligned}
$$

$$
\begin{aligned}
\text{Absolute Pressure, psi} &= \text{Atmos. Press., psi} + \text{Gage Press., psi} \\
&= 14.7\ \text{psi} + (-9.8\ \text{psi})^{*} \\
&= 4.9\ \text{psi}
\end{aligned}
$$

* — means a vacuum or negative pressure.

Note that the units of pressure are the same for liquids and gases.

3. *FLOW RATE*

Liquids: Flow rates for liquids are usually expressed as volume per unit time. The most common units are gallons per minute, gpm (gal/min), cubic feet per second (cfs or cu ft/sec) and million gallons per day (MGD). In each of the above cases, a given volume of liquid moves past a given point during a unit of time.

Gases: Flow rates for gases are usually expressed as cubic feet per minute (cfm or cu ft/min), cubic feet per hour (cfh or cu ft/hr), and cubic feet per day (cfd or cu ft/day). Many instruments are calibrated in SCFM where the S refers to **S**tandard conditions of temperature, pressure and humidity. The same flow rate definitions apply to gases as for liquids.

Solids: Flow rates for solids are commonly expressed as pounds per hour (pph or lbs/hr), pounds per day (ppd or lbs/day) or tons per hour. They also may be expressed in volumetric terms such as cubic feet per day (cfd or cu ft/day) or cubic yards per day (cyd or cu yd/day). Therefore, we may conclude that flow may be measured in terms of volume or weight.

4. *LEVEL*

The units for expression for level are usually expressed in terms of inches or feet (cm or m). However, in the laboratory, the metric units of measurement are used such as millimeter (mm), centimeter (cm), or meter (m).

5. *DENSITY*

Percent Solids: Although we have defined density as weight per unit volume, instrumentation in a treatment plant can be calibrated to read in percent solids for sludges.

Specific Gravity: The density of liquids is measured by a hydrometer expressing units of specific gravity (which is the ratio of specific gravity of a liquid to the specific gravity of water, which is one).

6. *VELOCITY*

Velocity measurements in a treatment plant are usually expressed in terms of feet per second (fps or ft/sec); feet per minute (fpm or ft/min); or for rotational velocities, in revolutions per minute (rpm or rev/min).

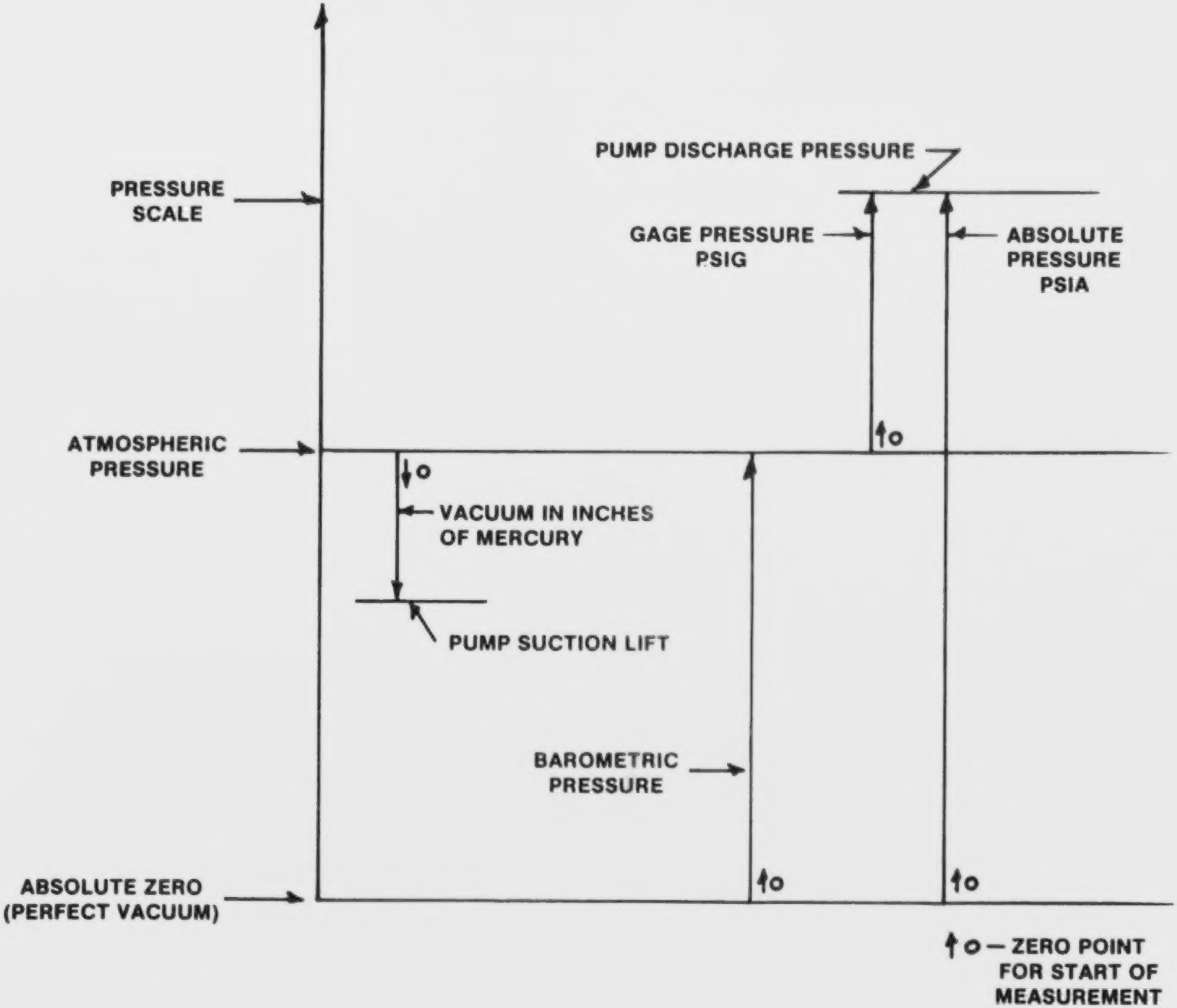
PUMP DISCHARGE PRESSURE
PRESSURE SCALE
GAGE PRESSURE PSIG
ABSOLUTE PRESSURE PSIA
ATMOSPHERIC PRESSURE
↑o
↓o
VACUUM IN INCHES OF MERCURY
PUMP SUCTION LIFT
BAROMETRIC PRESSURE
ABSOLUTE ZERO (PERFECT VACUUM)
↑o
↑o
↑o — ZERO POINT FOR START OF MEASUREMENT

Fig. 8.19 Measurement of pressures

7. *ANALYTICAL MEASUREMENTS*

Analytical measuring instruments are very specific in what and how they measure. Some of the units of expression for the more common analytical instruments found in a treatment plant laboratory are discussed in the next paragraphs.

pH meters read in units of pH; dissolved oxygen meters read in milligrams per liter (mg/*L*); and electrical conductivity meters usually read in mhos which are equal to 1/ohm.

There are also other more sophisticated laboratory instruments such as Total Organic Carbon Analysers, Gas Chromatographs, Infrared Spectrophotometers, Atomic Absorption Units, and others which are way beyond the capability of this section, and therefore will not be discussed further. Table 8.1 summarizes the common units of measurement.

TOTAL ORGANIC CARBON ANALYSERS
GAS CHROMATOGRAPHS
INFRARED SPECTROPHOTO METERS
AND OTHERS
ATOMIC ABSORPTION UNITS

QUESTION

Write your answers in a notebook and then compare your answer with the one on page 487.

8.2A Complete the following table by writing both the English and Metric units for the following variables measured by instruments or sensors.

Measurement	English	Metric
1. Temperature		
2. Pressure		
3. Flow		
4. Level		
5. Density		
6. Velocity		

END OF LESSON 1 OF 4 LESSONS ON INSTRUMENTATION

Please answer the discussion and review questions before continuing with Lesson 2.

TABLE 8.1 UNITS OF MEASUREMENTS AND ABBREVIATIONS

Measurement	Common Units of Measurement and Abbreviations	
	ENGLISH	
1. Temperature	a) Fahrenheit:	
	Freezing Point of Water = +32°F	
	Boiling Point of Water = +212°F	
	b) Rankine:	
	Freezing Point of Water = +491.7°R	
	Boiling Point of Water = +671.7°R	
	METRIC	
	c) Celsius or Centigrade:	
	Freezing Point of Water = 0°C	
	Boiling Point of Water = +100°C	
	d) Kelvin:	
	Freezing Point of Water = +273°K	
	Boiling Point of Water = +373°K	
	ENGLISH	*METRIC*
2. Pressure	a) Pounds per square inch = psi or lb/in²	kg/sq cm
	b) Pounds per square foot = psf or lb/ft²	kg/sq m
	c) Inches of water = inches H_2O	mm H_2O
	d) Feet of water = feet H_2O	m H_2O
	e) Inches of Mercury = inches Hg	mm Hg
	f) Absolute pressure = psia	kg/sq cm
	g) Gage pressure = psig	kg/sq cm
3. Flow	a) Liquids (volume)	
	gallons per minute = gpm or gal/min	*L*/sec or cu m/sec
	gallons per hour = gph or gal/hr	*L*/sec
	cubic feet per second = cfs or ft^3/sec	cu m/sec
	million gallons per day = MGD	cu m/day
	b) Gases (volume)	
	cubic feet per minute = cfm or ft^3/sec	*L*/sec or cu m/sec
	cubic feet per hour = cfh or ft^3/hr	*L*/sec
	cubic feet per day = cfd or ft^3/day	*L*/sec
	c) Solids or Liquids (weight)	
	pound per minute = ppmin or lbs/min	gm/sec
	pound per hour = pphr or lbs/hr	gm/sec or kg/hr
	pound per day = ppd or lbs/day	kg/day
	d) Solids (volume)	
	Cubic feet per day = cfd or ft^3/day	cu m/day
	Cubic yard per day = cyd or yd^3/day	cu m/day
4. Level	a) inches = in	mm
	b) feet = ft	m
5. Density	a) Percent solids = %	
	b) Specific Gravity = Sp.Gr.	
	c) Parts per Million = ppm	
6. Velocity	a) Linear:	
	feet per second = fps or ft/sec	m/sec
	feet per minute = fpm or ft/min	m/min or mm/sec
	b) Rotational:	
	Revolutions per minute = RPM	RPM
7. Analytical	a) Hydrogen Ion Concentration = pH	pH
	b) Dissolved Oxygen = ppm or mg/*L*	mg/*L*
	c) Electrical Conductivity = mhos	mhos
8. Energy or Work	foot – pounds	joule
9. Power	foot – pounds/sec or horsepower	joule/sec or watt

DISCUSSION AND REVIEW QUESTIONS

(Lesson 1 of 4 Lessons)

Chapter 8. INSTRUMENTATION

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson.

Write the answers to these questions in your notebook.

1. Why do treatment plants have instruments and controls?
2. Why are some instruments more accurate, consistent and sensitive than human senses?
3. How would you measure the depth of water in a wet well?

CHAPTER 8. INSTRUMENTATION

(Lesson 2 of 4 Lessons)

8.3 HOW DO INSTRUMENTS (SENSORS) MEASURE?

Now that we are familiar with the units of measurements expressed by instruments, let's examine in a simple manner how treatment plant instruments function. The operator must be reasonably familiar with what makes instruments "tick" in order to determine if an instrument or control is operating properly or if a problem exists.

Due to a wide and ever-expanding variety of instrumentation and control systems, only the most common types that an operator might work with will be discussed in this section.

1. *TEMPERATURE*

Temperature measurements involve the transfer of heat or cold between the material whose temperature is being measured and the temperature sensing instrument. Let's examine the workings of several of the more common temperature-sensing instruments.

A. *LIQUID-FILLED THERMOMETER*

Everyone is familiar with this device, a sealed, hollow glass tube filled with liquid. Let us examine how a mercury filled thermometer works. Mercury expands when heated. Consequently, when heat is applied to or removed from a mercury thermometer, the volume of mercury expands or contracts at a much greater rate than the glass tube containing the mercury. This forces the mercury to move up or down a precise amount for each degree change in temperature. The amount of mercury movement and sensitivity of the thermometer depends on the size (diameter) of the bore of the glass tube. The outside of the glass tube is equally subdivided to correspond to the change in mercury volume as a function of the change in temperature.

All liquid-filled thermometers work on the stated basic principle that the liquid inside the thermometer expands at a greater rate than the glass tube surrounding it and the distance of movement in the tube is calibrated in degrees. A variation of this principle uses a bulb containing the temperature sensitive liquid which is connected to a capillary tube in which the expanding liquid travels up or down in the tube (Fig. 8.20). The capillary tube is connected to a specially shaped hollow tube which bends as the liquid from the capillary tube enters or leaves it. The free end of the hollow tube is connected to a mechanical linkage which is calibrated to indicate the change in temperature.

Still another variation of the above principle uses a gas as the expanding media in the bulb instead of the liquid; otherwise, they are quite similar in operation and principle.

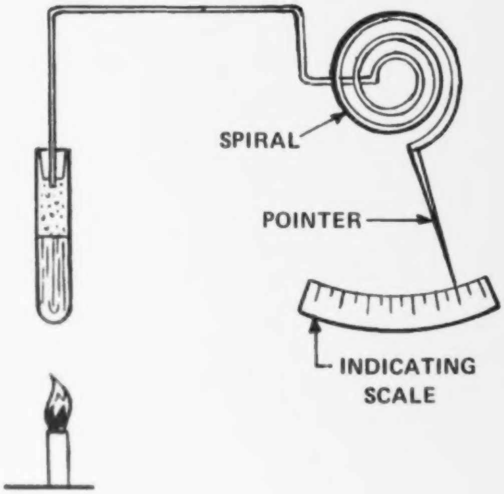

Fig. 8.20 An expanding or contracting fluid may be used to measure temperature.

B. *BIMETALLIC THERMOMETER*

In a bimetallic-type of temperature measuring device, two metals with different rates of thermal expansion are fused together. When heat is applied to the bimetallic element which has one end fixed, the metal with the greater coefficient of thermal expansion expands a greater amount and causes the bimetallic element to bend or flex. The amount of bending is called "flexivity." The bending end of the bimetallic element is mechanically connected to a pointer which indicates the temperature change in degrees.

C. *THERMOCOUPLE*

Simply stated, a thermocouple is a device consisting of two different types of metallic wires joined together, which when heated produce an electrical voltage (electromotive force or EMF). The voltage produced is proportional to the amount of heat applied at the junction of the two different metals and can be read by a millivoltmeter which is calibrated so as to convert the change in voltage to the corresponding change in temperature (see Fig. 8.21).

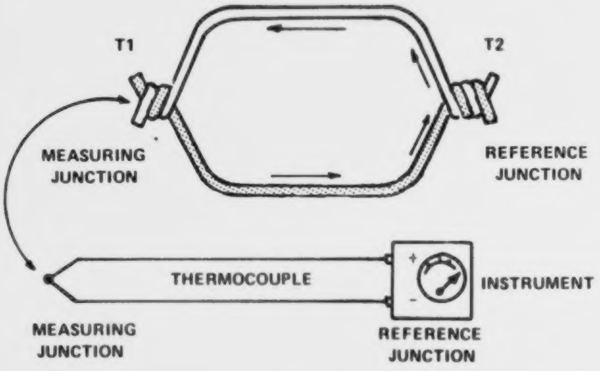

Fig. 8.21 A thermocouple is used to measure temperature.

So far we have examined several ways of sensing temperature. Each method has its most suitable application based on such factors as temperature range, accuracy, sensitivity, costs, durability, and corrosion resistance.

2. *PRESSURE*

We defined pressure as the amount of force applied to a unit area. For our purpose, we will be primarily concerned with gage pressure which is the amount of pressure shown on the pressure-measuring instrument. Let us examine how several common pressure-sensing (measuring) instruments function.

A. *MANOMETER*

A manometer is a liquid-filled glass tube device (Fig. 8.22). The liquid is raised or lowered by the pressure exerted by the fluid (liquid or gas) being measured. Different ranges of pressure may be measured by changing the liquid in the manometer to one of a lower or higher specific gravity; water and mercury are the most common liquids used. The sensitivity of a manometer also may be increased by inclining (sloping) the measuring leg of the manometer rather than using a vertical measuring leg.

The applied pressure on one tube of a U-tube manometer (the other tube is open to atmospheric pressure) is equal to the total vertical height of the liquid column times the density of the liquid.

$$\text{Pressure, lbs/sq ft} = \text{Height, ft} \times \text{Density, lbs/cu ft}$$

$$\text{or} \quad \text{Pressure, lbs/sq in} = \text{Height, in} \times \text{Density, lbs/cu in}$$

When pressure is applied to both tubes of a U-tube manometer, the differential pressure may be read directly without regard to the actual pressures involved. Again, in this case, the differential pressure is equal to the height of the liquid column times the density of the manometer liquid (Fig. 8.23).

$$\begin{aligned}\text{Differential Pressure, psi} &= P_2\text{, lbs/sq in} - P_1\text{, lbs/sq in}\\ &= \text{Height, in} \times \text{Density, lbs/cu in}\end{aligned}$$

When reading the U-tube manometer, the value of h is the difference in height between the top of the liquid of the left and right legs of the U-tube. To eliminate this step, a well manometer can be used. In this type of manometer, the area of the well is large enough in comparison to the bore of the manometer so that the applied pressure may be read directly (Fig. 8.24). Also, the scale of the manometer may be made (calibrated) to compensate for the drawdown of the fluid in the large well.

$$\text{Pressure, psi} = \text{Height, in} \times \text{Density, lbs/cu in}$$

B. *PRESSURE GAGES*

The most common types of pressure-measuring instruments use some type of element that undergoes elastic deformation (bends or flexes and then returns to its original shape or location). Both low and high pressures may be measured with gages employing this principle.

BOURDON TUBE (Fig. 8.25)

The Bourdon Tube is one of the most common pressure element devices employing the elastic deformation principle. The element consists of a thin metal tube, elliptical in cross section, formed into a "C" shape; one end of the "C" is rigidly attached to a socket where the pressure to be measured is applied, the other free end is mechanically linked to a gage movement which is calibrated to indicate the desired pressure units. When pressure is applied to the "C" shaped tube, it begins to straighten (unwind) out (just like a New Year's Eve party blower). The amount of movement caused by the straightening out process is not linear; it moves more per unit pressure at first and then decreases in the amount of movement as the pressure increases. Therefore, only a small part of the possible movement is used to measure pressure. A 0 to 60 psi (4.22 kg/sq cm) element will move only 0.25 of an inch (0.64 cm).

In elastic deformation elements, pressures in excess of that designed for a particular unit will deform the element and it will not return to zero (or original shape), thus ruining the gage. Lower pressure elements are usually made of copper alloys; some of the higher pressure elements are made of carbon steels.

DIAPHRAGM OR BELLOWS ELEMENTS

Another type of elastic deformation pressure element is the diaphragm or the bellows (Fig. 8.26). In both of these systems, the applied pressure deforms (moves) the diaphragm or the bellows a small amount. The amount of movement is mechanically linked to a gage movement for expression of the applied pressure. Diaphragm- and bellows-type pressure elements are commonly used for low pressures such as 0 to 10 inches (25.4 cm) of water. Although the bellows are

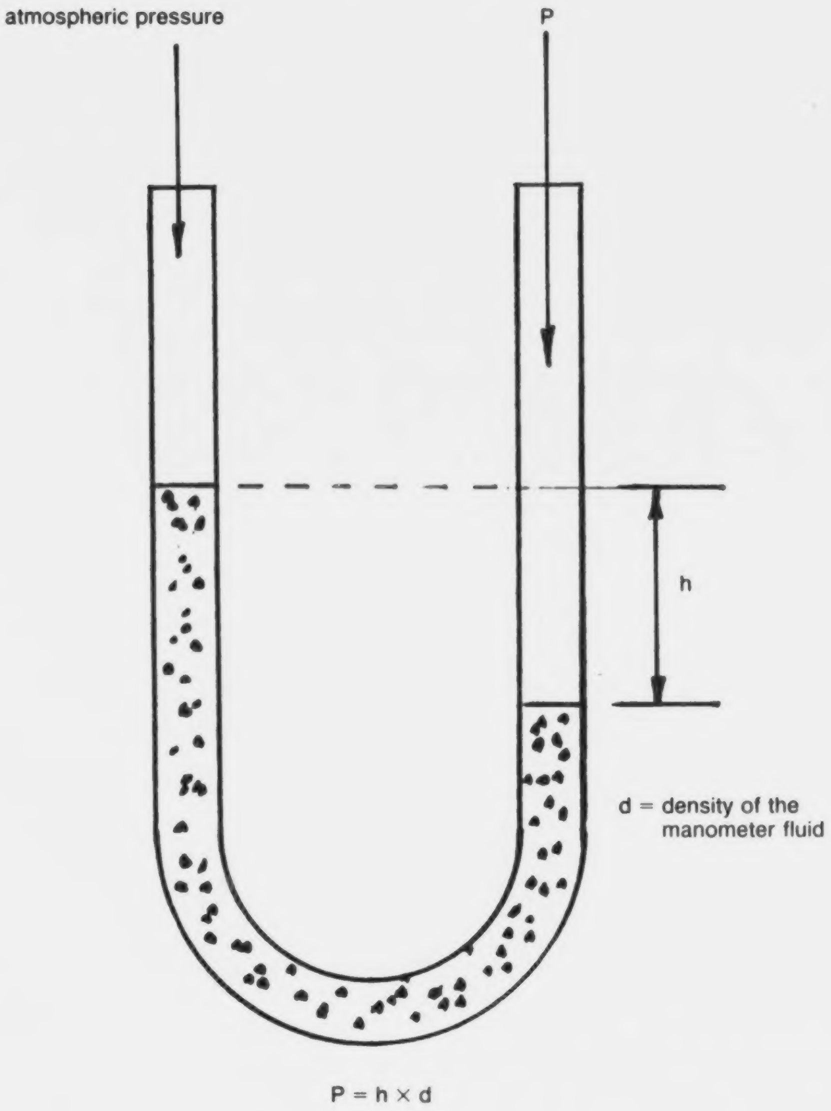
atmospheric pressure
P
h
d = density of the manometer fluid
P = h × d

Fig. 8.22 A simple U-tube manometer used to measure pressure.

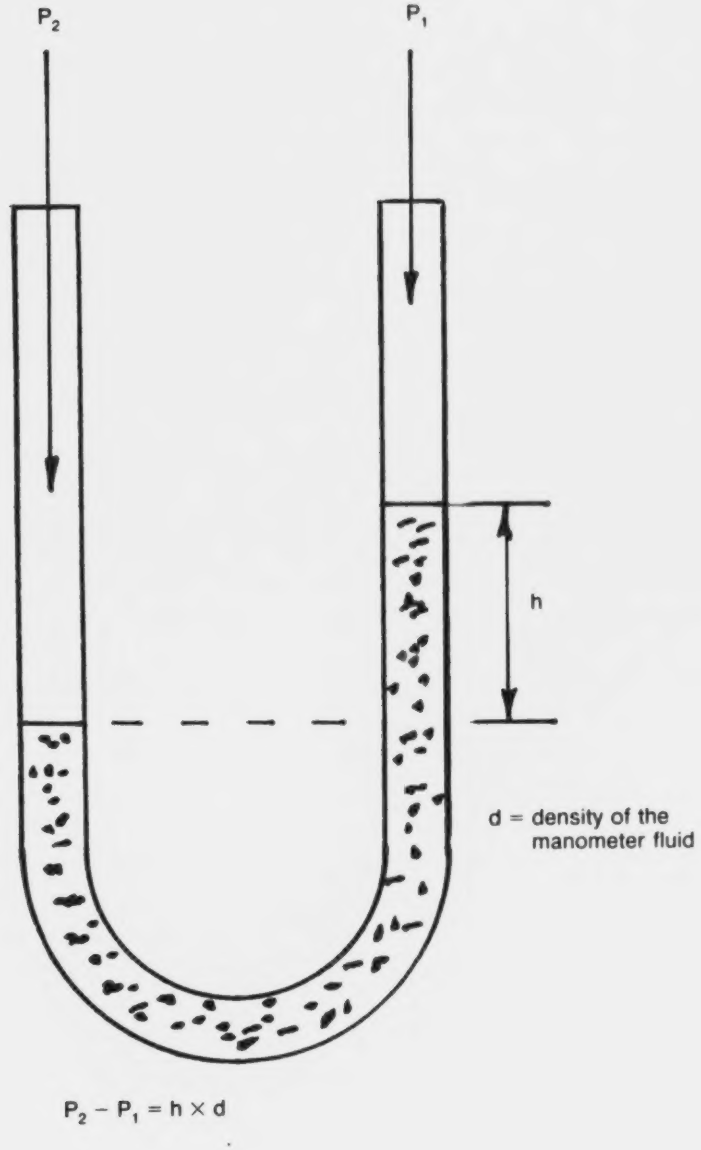
P_2
P_1
h
d = density of the manometer fluid
$P_2 - P_1 = h \times d$

Fig. 8.23 A U-tube manometer used to measure a differential pressure.

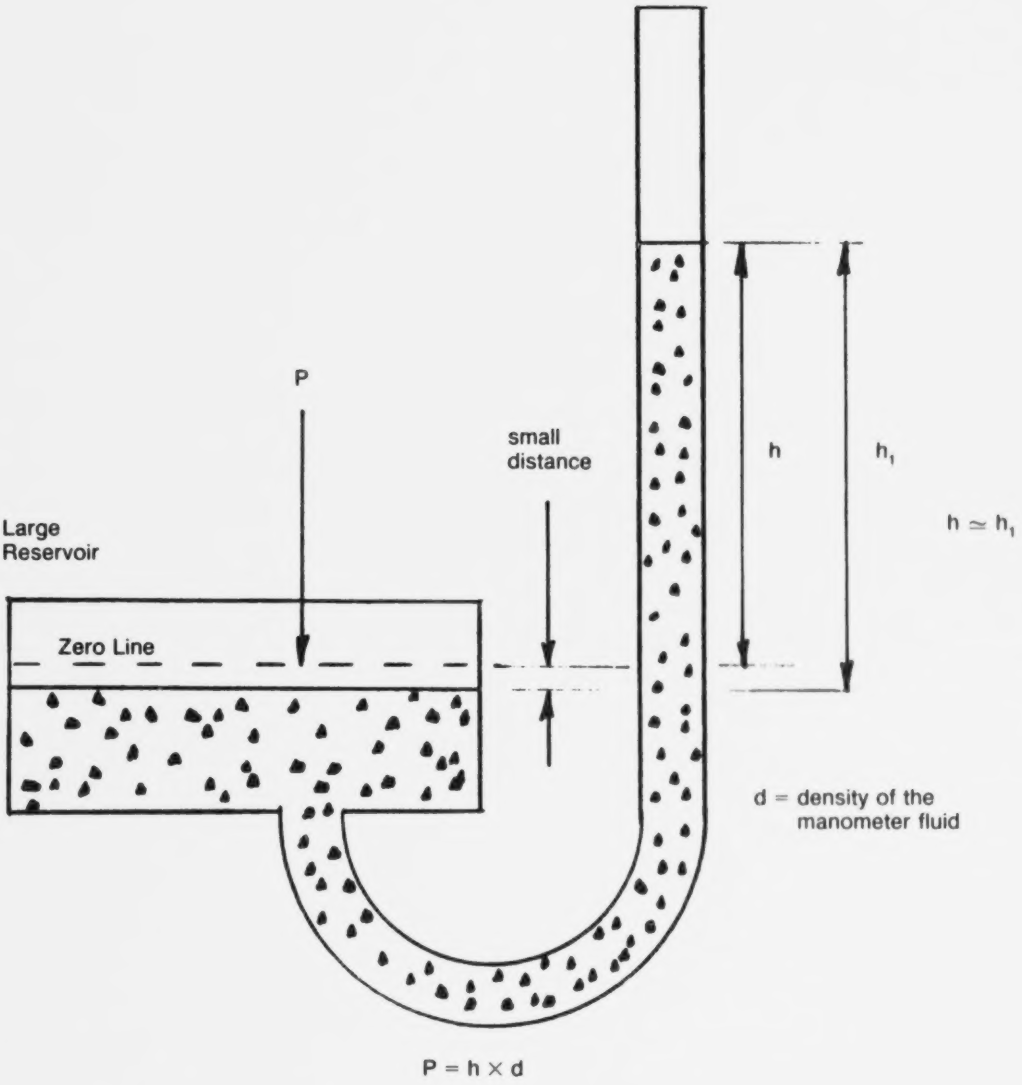
P
small
distance
h
h_1
$h \simeq h_1$
Large
Reservoir
Zero Line
d = density of the
manometer fluid
$P = h \times d$

Fig. 8.24 A wet-well manometer used to measure pressure.

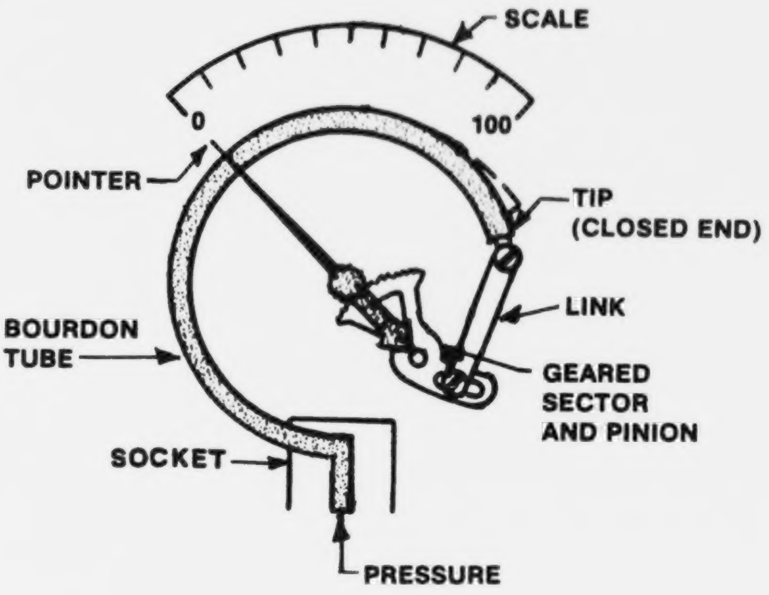
SCALE
0
100
POINTER
TIP
(CLOSED END)
LINK
BOURDON
TUBE
GEARED
SECTOR
AND PINION
SOCKET
PRESSURE

Fig. 8.25 A Bourdon tube is used to measure pressure.

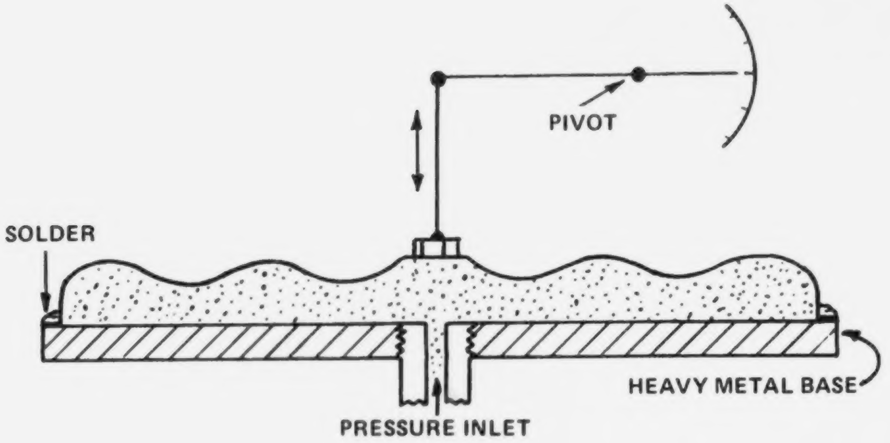
PIVOT
SOLDER
HEAVY METAL BASE
PRESSURE INLET

Fig. 8.26 A metal diaphragm is used to measure pressure.

usually constructed from metals, the diaphragms can be made from different materials depending upon the application, such as the need for a corrosion-resistant material.

3. *FLOW*

There are several different types of instruments used to measure flow in either pipes or open channels. All of these instruments attempt to measure the flow velocity and area.

Flow or Quantity = Area × Velocity

= AV

or Q, cu ft/sec = Area, sq ft × Velocity, ft/sec

Many flow meters estimate the velocity by measuring the difference in pressure as the fluid flows through a restriction such as an orifice or a Venturi. Because flow measurements are so important to the operation of a wastewater treatment plant, this topic was covered in Chapter 15, "Maintenance," Section 15.4, "Flow Measurements," Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS*. Flow measurements are used by operators to determine what and how many units of treatment plant facilities must be on-line at any one time. Daily flows are used to calculate plant loadings and plant efficiencies.

4. *LEVEL*

The simplest and most direct means of measuring levels for clean liquids is the sight tube. However, it may not be practical to install a sight tube in many applications, therefore, other level-measuring devices are employed.

A. *FLOAT SYSTEM*

A float tied to a cable or rod is one of the most commonly used level-measuring devices. The float rests on the surface of the liquid being measured and rises or falls with the liquid surface. In another system, the float is connected to a mechanical linkage and the buoyancy of the float is used to signal the liquid level (Fig. 8.27).

B. *ELECTRIC PROBE*

Electric probes are commonly used to measure a single level, such as a high- or low-level alarm. In the case of the high-level alarms, the rising liquid allows an electrical current to flow between two contacts in the probe. When the current flows, a relay is tripped which energizes a secondary signal. In the low-level situation, the reverse is true. When the liquid drops below the probe, the electrical current stops flowing and causes another relay to activate another secondary signal.

C. *CAPACITANCE PROBE*

Similar to electric probes, capacitance probes are also used. In this system, the capacitance (an electrical term used to measure the capability of holding an electrical charge) changes when the liquid is in or out of contact with the probe, which in turn actuates a relay, which can trip a secondary device or send a signal.

D. *ULTRASONIC SOUND*

Another type of probe is the ultrasonic probe. This device uses a miniature transmitter and receiver at the end of the probe. The signal sent by the transmitter to the receiver changes when the probe is in or out of the liquid, which in turn activates a relay system to perform the necessary function.

The ultrasonic system also may be used to constantly monitor the process level. In this system the transmitter and receiver are mounted on top of the tank and the time interval it takes for a transmitted ultrasonic sound signal to be reflected off the liquid surface or solid being measured and bounced back to the receiver is electronically translated into a level measurement (Fig. 8.28).

E. *DIAPHRAGM BOX*

The diaphragm-box level indicator uses a sealed box containing a flexible diaphragm exposed to the liquid being measured. The hydrostatic pressure exerted upon the submerged diaphragm causes the volume of the sealed box to fluctuate with the changes in liquid level; this change in air volume (pressure) is transmitted through a tube to a pressure gage calibrated to read in inches or feet (centimeters or meters).

F. *BUBBLER TUBE*

The bubbler tube uses air pressure to measure liquid levels. This system is based on the required air pressure necessary to overcome the hydrostatic pressure at the bottom of a container. In practice, a tube is vertically lowered into a container and the air pressure increased to the point where water is blown out of the tube and air bubbles begin to flow out. The *PRESSURE REQUIRED* to force air out of the tube *VARIES WITH THE LIQUID LEVEL* and this relationship is converted to level measurement. This particular system is applicable only to liquid surfaces open to the atmosphere and cannot be used for sealed containers (Fig. 8.29).

5. *DENSITY*

Process density measurements in a treatment plant are usually made for primary sludge or return activated sludge concentrations in a pipeline. Almost all of the measuring instruments use the principle of sending a signal across the sludge flow path and relating the density of the sludge to the strength of the signal received. This is based on the fact that the greater the density of the sludge, the greater the attentution (reduction) in signal strength. The signal source may be a radioactive cell, an ultrasonic sound wave, or a light beam. The reduction in signal strength is usually calibrated against flows with known solids concentrations and the instruments are adjusted to read accordingly.

6. *VELOCITY*

Usually the only velocity measurement made in a treatment plant is rotational velocity or RPM. This is commonly accomplished by some type of tachometer.

An electro-mechanical tachometer uses a flexible cable or some other device to pick up the rotating movement. The tachometer may use a gear box to increase or decrease the rotating motion. This rotating movement is used to drive a small electrical generator whose electrical output is calibrated in RPM (revolutions per minute). The faster the RPM the higher the electrical output and visa versa.

Another tachometer system uses a strobe light. The frequency of the strobe light is adjusted until the motion of the equipment whose rotation is being measured appears to stop or stand still. This frequency is then converted into the equivalent RPM.

An electrical tachometer consists of a transducer which converts rotational speed into an electrical signal coupled to an indicator or recorder. One type of transducer is a magnetic pickup head which produces electric pulses each time a tooth of a rotating gear passes. The pulses can be digitally counted and displayed in terms of revolutions per minute.

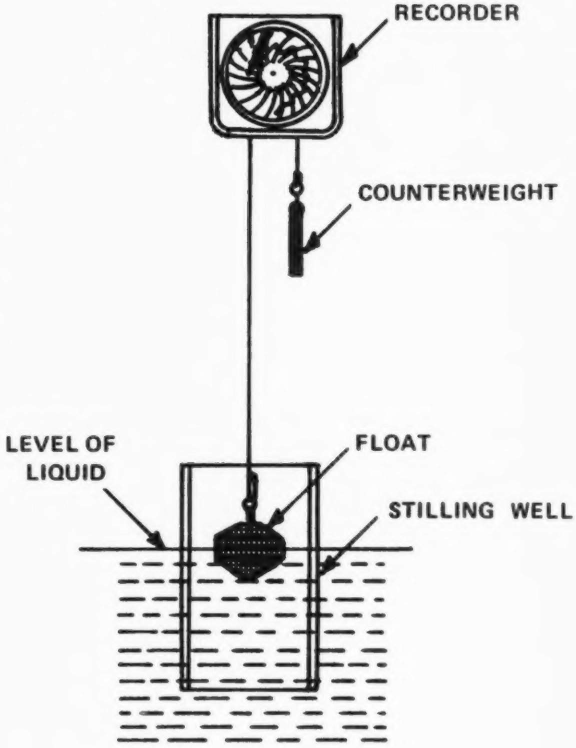
RECORDER
COUNTERWEIGHT
LEVEL OF LIQUID
FLOAT
STILLING WELL

Fig. 8.27 A float is used to measure liquid level.

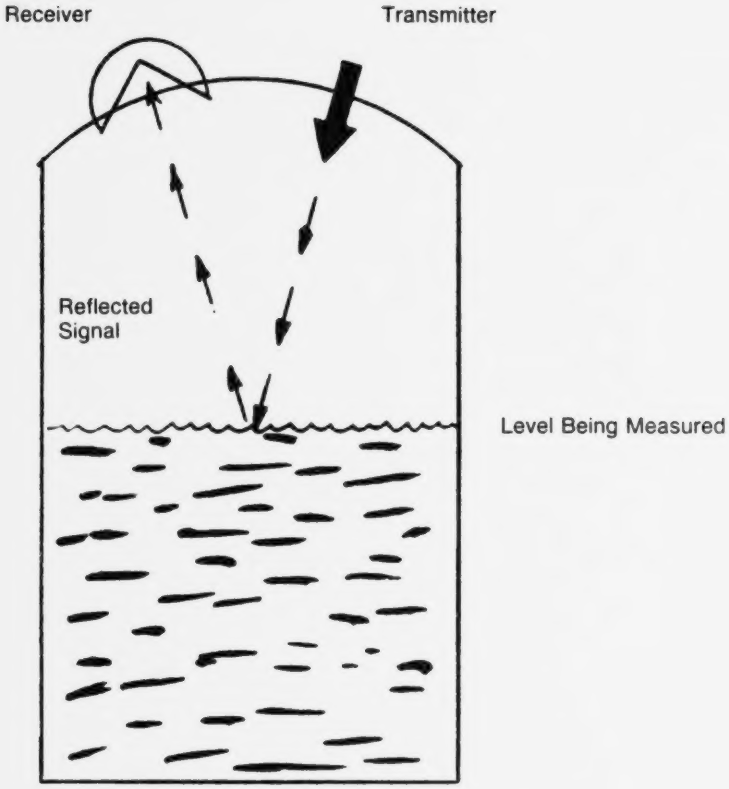
Receiver
Transmitter
Reflected Signal
Level Being Measured

Fig. 8.28 Ultrasonic sound is used to measure liquid levels.

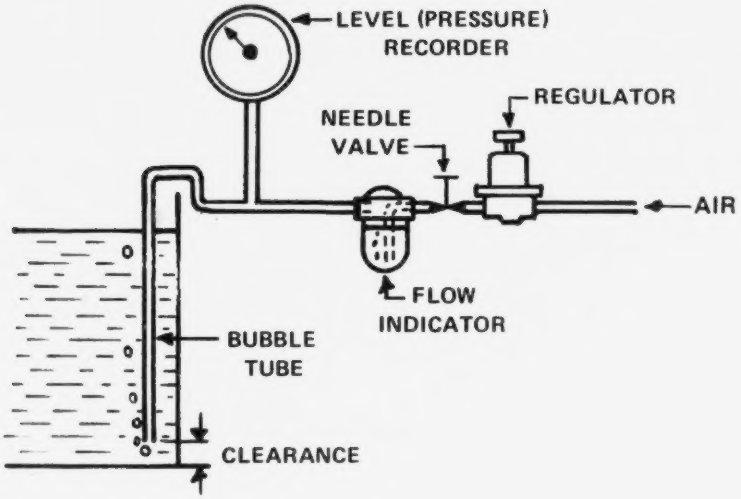
LEVEL (PRESSURE) RECORDER
REGULATOR
NEEDLE VALVE
AIR
FLOW INDICATOR
BUBBLE TUBE
CLEARANCE

Fig. 8.29 A bubbler tube is used to measure liquid level

7. *ANALYTICAL MEASUREMENT*

Most analytical instruments are more fragile, sophisticated, and expensive and also require a greater degree of attention than do most of the routine treatment plant process instruments. These analytical instruments are used mainly in the laboratory. Consequently, their theory of operation is beyond the scope of this section which has been devoted to familiarizing the operator with the basic instruments used in process control.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.3A List three different types of temperature-measuring instruments or sensors.

8.3B What are the most common liquids used in manometers to measure pressures?

8.3C Determine the pressure in psi if a manometer reads:

1. 8 inches of water; and
2. 8 inches of mercury.

Assume water has a density of 62.4 lbs per cubic foot and that mercury has a specific gravity of 13.55.

8.4 INDICATORS

We have examined some measuring tools such as rulers which give a direct measurement. Other instruments require a secondary device to make the measurement. For example, a thermocouple needs an electrical meter to indicate and translate voltage (electrical pressure) into temperature readings. The indicators may be as simple as a notch on an oil level dip stick or as complex as a digital readout on a Cathode Ray Tube (CRT) connected to a computer. Indicators also are known as the measuring element and are a part of most instrumentation systems (Fig. 8.30). The indicator may be visual or audio (sound sensed).

Visual indicators usually consist of two major parts, the fixed or moveable scale (unit of measurement) and a movable indicator. In some cases, the fixed scale may be as simple as color coding, such as green for "OK" and red for an unacceptable situation. Most of the indicators in a treatment plant use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart.

The scales on an indicator may be straight, curved, or circular in shape. The scale divisions (units of measurement) also may be uniformly divided or unequally divided. For example, a liquid-filled theromometer has equal uniform divisions, but an ohm meter (measure of electrical resistance) has unequally divided scale divisions.

In most cases the units of measurement are direct reading, such as a pressure gage indicating the pressure in psi. However, in some cases it may be necessary to convert the gage reading into some other unit of measurement. An example of this would be a mercury filled U-tube manometer reading 10 inches (24.4 cm) of mercury. We would have to divide the 10 inches of mercury by 2.04 inches of mercury per psi to get a pressure of 4.9 psi.

$$\text{Pressure, psi} = \frac{\text{Height, inches of mercury}}{\text{2.04 inches of mercury/psi}}$$

$$= \frac{\text{10 in. Hg}}{\text{2.04 in. Hg/psi}}$$

$$= \text{4.9 psi}$$

The same type of situation could exist for temperature readings from thermocouples which produce a signal in millivolts which would be converted to degrees by multiplication or division by a conversion factor (K).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.4A What is the purpose of transmitting instruments?

8.4B What are the different types of receivers?

8.5 CONTROLLERS

8.50 What are Controllers?

One of the basic objectives of an instrumentation system is the automatic control of measurable process variables (flow, pressure, level, or temperature). Therefore, by the use of primary measurement elements and controllers we automatically measure the process variable, compare it with the desired value (*SET POINT*[2]) and institute some corrective action (change the energy level) if the measured process variable is different from the desired range of values. The process variable also may be simultaneously recorded or monitored as needed.

We will examine some simple process control functions used in treatment plants. Remember that there are many ways to accomplish process control and each system should be tailored to meet the needs of your treatment plant. Usually there are five parts to a control system.

1. *PRIMARY ELEMENT OR SENSOR*

The primary element or sensor is the instrument that measures (senses) a physical condition or variable of interest. A float or a thermocouple would be an example of a primary element. We have just examined many of these types of devices.

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[2] *Set Point. The position at which the control or controller is set. This is the same as the desired value of the process variable.*

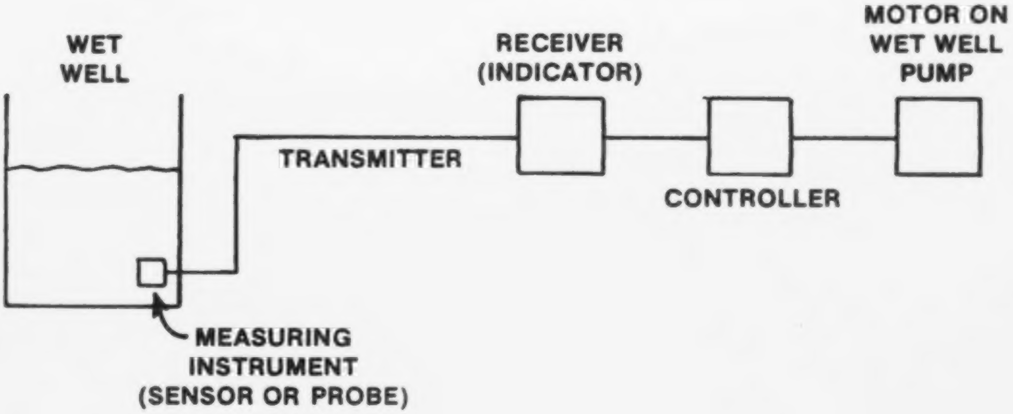

WET WELL
RECEIVER (INDICATOR)
MOTOR ON WET WELL PUMP
TRANSMITTER
CONTROLLER
MEASURING INSTRUMENT (SENSOR OR PROBE)

Fig. 8.30 Instrumentation system.

2. *TRANSMITTER*

A mechanical, hydraulic, pneumatic, or electrical system that transmits a signal from the primary element to the receiving element, and/or control device.

3. *RECEIVING ELEMENT OR RECEIVER*

The receiving element receives the signal or output of the primary element.

The millivolt meter connected to the thermocouple is an example. Another example would be the pressure gage that expresses the level in a diaphragm-box level system.

4. *CONTROLLING ELEMENT OR CONTROLLER*

The controlling element or controller is the device that reacts to the changes in the measured variable. The device may react pneumatically, electrically, mechanically, or hydraulically depending upon the application. An example of this would be an electrical relay connected to the pressure gage from a diaphragm box. Whenever the level reached a previously determined set point, it would cause the pressure gage mechanism to physically move. This movement would trigger a relay to perform some secondary action, such as turning off (switching off) the pump to the tank.

5. *FINAL ELEMENT*

The final element is the device that controls the energy supplied to the process being controlled. The final element could be the pump being turned-off (as in the previous example) or it could be a more sophisticated system where several valve openings would be modulated (changed).

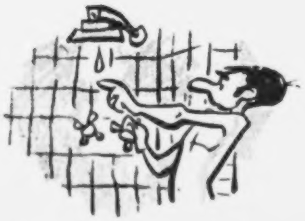
In the previous pressure diaphragm box example, the liquid in the tank is the controlled medium, the controlled variable would be the liquid level in inches or feet (centimeters or meters), and the manipulated variable is the pump being turned on or off. The set point would be a predetermined maximum level the operator selects for the tank. The set point also may be called the control point.

The control system may or may not include facilities to visually or audibly monitor or record the process. Systems which automatically control without indicating the control process are called "blind" systems.

In summary, a control system is a series of devices which measures, compares, controls an energy source, and finally causes some action to be taken automatically to maintain a previously established or desired control variable. The controller may perform this function with or without visual indications or verifications.

8.51 How Do Controllers Work?

The human body is an excellent example of a controller. Let us examine how it works. In the very beginning of this chapter, we used the example of a person opening a door. However, for this example let us have a person desiring warm water for a shower. In this example, the eyes and skin would be the primary sensing elements. The nerves would be the transmitter. The brain would be the receiver and also measuring and controlling elements and the hands would be the final element. When a person first enters a shower, the eyes sense that the shower water is off. The brain measures this message and compares it with the set point of warm water. The brain then activates the hand to turn on both the hot and cold shower faucet handles. If the desired warm water comes out, no other action is initiated since the skin signals (feedback) to the brain that all is "OK." However, if the water is too warm or too cold, the skin signals the brain which again measures the signal from the sensing element (skin) and compares it to the desired set point (warm water) and then signals the right or left hand to adjust either the hot or cold water faucet. This feedback process automatically continues until the desired set point is reached.



Although we have defined what controllers (control elements) are and discussed how a system would operate, we need to better define some of the terminology (name of) and specific control methods.

OPEN AND CLOSED LOOPS

Control systems are divided into two general categories, (1) open loop, and (2) closed loop systems. In an open loop system, there is no information fed back to the controller to change the control function. An example of this would be an automatic lawn sprinkler system operated by a clock-timer. The sprinkler system will operate at the set time every day and for the set watering duration, regardless of whether it is raining or not. In an automatic closed loop system, a moisture sensing device would be added to the sprinkler control system which would tell the controller not to water during a rain or when a moist ground condition exists. In other words, a closed loop system incorporates some sort of feedback mechanism to modify the behavior of the controller.

MANUAL CONTROL

The simplest control system is the manual control system in which the operator senses, measures, and initiates any necessary action. Assuming the operator is alert, it is the most flexible and sophisticated system available since it uses the massive resources and adaptability of the human brain. Our brain probably will never be completely surpassed. However, one of the weaknesses associated with manual control is the lack of consistency or uniformity, since no two people think or act alike, and the human senses are not adequate to monitor all process situations.

ON-OFF CONTROL

The thermostat control for heating is a good example of on-off control. If the set point is set at 68°F (20°C), the controller will turn the heater on at about 67°F (19°C) and shut it off at about 69°F (21°C). Another way to look at it is that the final control element has only two positions (heater on or heater off).

PROPORTIONAL CONTROL

The next more complex level in control systems is the proportional control mode. This system has the capability to give the final control element varying intermediate positions besides on and off. The amount of control exercised is dependent upon how much deviation (difference) exists between the set point and the measured variable (*OFFSET*[3]). An example of this would be three pumps connected to fill a tank. The proportional control system would turn one pump on if the level dropped to ¾ depth; turn two pumps on if that level dropped to ½ depth; and turn on all three pumps if the level dropped to ¼ depth. In other words, the degree of control exercised would be proportional to the need, but the degree of control exercised will not change until the measured variable changes. In this example, three pumps would remain on as long as the level did not exceed ½ depth.

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[3] *Offset (or Droop). The difference between the actual value and the desired value (or set point) characteristic of proportional controllers that do not incorporate reset action.*

PROPORTIONAL CONTROL WITH RESET

Proportional control with reset is a proportional control system with the addition of reset control. Reset control may be thought of as a correction device that cannot function by itself. What reset control does is provide a correction signal to minimize the amount and time the measured variable deviates from the desired set point. As an example, if the control system for a gas water heater had proportional control only, it would regulate the amount of gas sent to the burners based on the amount of water temperature deviation from the set point. However, if we also had proportional control with reset, the reset portion would also fire an additional burner to reduce the amount of time for the measured variable (temperature of water) to reach the set point (water temperature).

PROPORTIONAL CONTROL WITH RESET AND DERIVATIVE

The next more complex control system adds a derivative function to proportional control with reset.

The derivative function controls the rate at which the corrective action takes place based upon the rate at which the measured variable is changing. Therefore, if the control system senses (measures) a slow or small amount of deviation occurring, the proportional control system would most likely handle the situation. However, if a large or rapidly occuring deviation was measured, the derivative control would attempt to increase the action taken by the final element to minimize the amount and time period that the measured variable was under or over the set point.

Let's again use the person desiring warm water for a shower as an example. The measuring elements are the eyes and skin; the measured variables are the water temperature and volume; the control element is the brain, and the final elements are the hands. With on and off control only, the hot and cold water would turn on or off. If we add proportional control, we would turn the faucet on or off proportional to the amount of hot or cold water we desired based on the temperature of the shower water. If we add reset, we would control or turn the hot or cold faucet in anticipation of the water temperature changing due to the *TIME LAG*[4] between the faucet and shower head. Finally, if we add derivative control, we would control the rate at which we turned the faucet handle. That is to say if we were close to the desired water temperature we would turn the faucet handle a small amount very slowly. However, if we were being scalded with very hot water, we would most rapidly turn the hot water off and the cold water on.

RATIO CONTROL

Ratio control is a closed loop system where two or more variables are mixed or metered at a predetermined ratio. An example of ratio control is the blending of two liquids such as adding polymer to wastewater (Fig. 8.31). In this case, the main line flow (wastewater) signal goes to the controller. The controller sends a signal to the secondary flow-control valve (polymer) to control the amount of polymer added. The flow of polymer is also measured and a signal is sent back to the controller to determine if the required amount is being added (closed loop control).

So in summary, we have discussed in simple terms the different classes of controllers and how they are supposed to perform. The actual working components of controllers are complex and sophisticated and some of the features of controllers such as Bandwidth, Reset Rate, and others have been left out for the sake of clarity. In addition, program controllers which control on the basis of time and Cascade controllers which use two controllers for a wider range of controls may also be found in a treatment plant, but have not been included in this discussion in an attempt to keep explanations as simple and straight forward as possible.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 487.

8.5A List the five common parts to a control system.

8.5B What are the common types of control methods?

8.6 RECORDERS

8.60 What Are Recorders?

We have discussed "Indicators" (measuring elements) which usually give some visual indication of process status. However, in many cases it is necessary to keep a continuous and permanent record of process variables. To obtain a continuous and permanent record, we normally use some sort of recording device, commonly called a "Recorder".

A recorder is a device that records information onto a sheet of paper that is moving at a specified speed. In this manner, the value of the process variable at any given point in time may be retrieved. Although this information could be taken manually by an operator reading a visual indicator and noting the time, it would be a very burdensome procedure especially if many process variables were to be continuously monitored. Also, in some instances the frequency or location of monitoring required may make it impractical to use operators. Recorders are more practical than having operators take readings every second or take readings in the middle of the night at remote locations where there are no operators.

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[4] *Time Lag. The time required for processes and control systems to respond to a signal or to reach a desired level.*

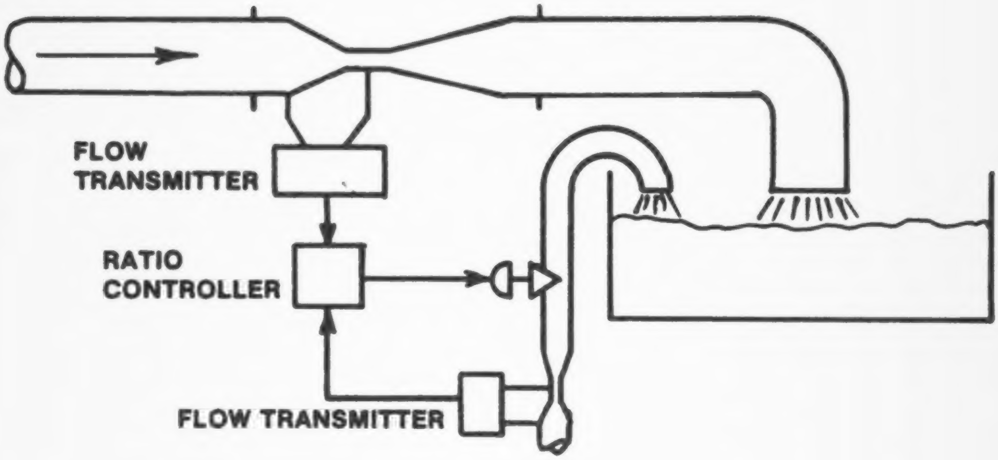

FLOW
TRANSMITTER
RATIO
CONTROLLER
FLOW TRANSMITTER

Fig. 8.31 Ratio control system.

8.61 Types of Recorders

There are two basic types of recorders found in a treatment plant. One type uses a circular chart and the other type uses a long strip of paper (Fig. 8.32). In both cases, the papers have lines indicating the various levels of process variables and time.

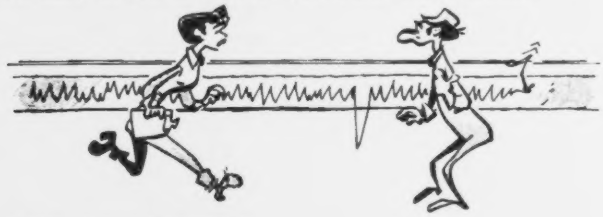
8.210 Circular Chart

In the circular chart, the process variable coordinates are concentric circles radiating outwards and the time frame is shown as arcs crossing the concentric circles. Circular flow charts are sometimes referred to as polar or polar graphic charts.

The chart is mechanically rotated at speeds between 15 minutes and 28 days per revolution, thus covering a wide range of time periods. The size of the chart may vary between 3 and 12 inches (7.5 and 30 cm) in diameter. Circular charts may use up to four recording pens. Each pen records a different variable or measurement.

8.611 Strip Chart

The other commonly used type of recorder is called a "Strip Chart Recorder." Strip charts use a long continuous piece of paper to record data. The chart may move horizontally or vertically with the time frame axis printed horizontally for horizontal recorders and vertically for vertical recorders. The strip may be up to 12 inches (30 cm) in width and available in various lengths. The speed of the strip chart may be moved rapidly for special recordings. The strip may be rolled up or "Z" folded after being marked. Strip charts also have the capability of operating twelve or more marking pens simultaneously.



8.612 Recording Media

Most circular or strip chart recorders use some sort of pen to record the information. Numerous means of inking the pen have been devised to prevent skipping or smearing of ink. In some units ball point, felt tip, electrical stylus, or some other marking device may be used.

8.613 Mechanisms

Recorder mechanisms will vary depending upon what is being recorded. Some circular chart pressure recorders use a modified Bourdon Tube mechanism and a spring-wound clock motor to move the chart. This design does not require any external power source and is suitable for field use. Other recorders require some source of power supply for the chart drive and recording pen mechanisms.

8.7 INTEGRATORS OR TOTALIZERS

Integrators or totalizers are devices that add and/or multiply. They are calculating devices which may operate continuously or intermittently. Some of the devices are mechanically operated and others are electrically powered. They may tally up the amount of digester gas produced or count the number of times a booster pump is switched on. Integrators are sometimes called summators or totalizers. A common example of an integrator would be the odometer on your car's speedometer.

Their basic use in a treatment plant is to sum up the amount of liquid or gaseous flow. This is commonly done by updating a digital counter. The operator usually subtracts the numbers recorded from the previous time period to determine the quantity that was produced or used.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.6A What is the purpose of recorders?

8.6B List the two basic types of recorders found in treatment plants?

8.7A What is the basic use of integrators or totalizers in treatment plants?

END OF LESSON 2 OF 4 LESSONS
ON
INSTRUMENTATION

Please answer the discussion and review questions before continuing with Lesson 3.

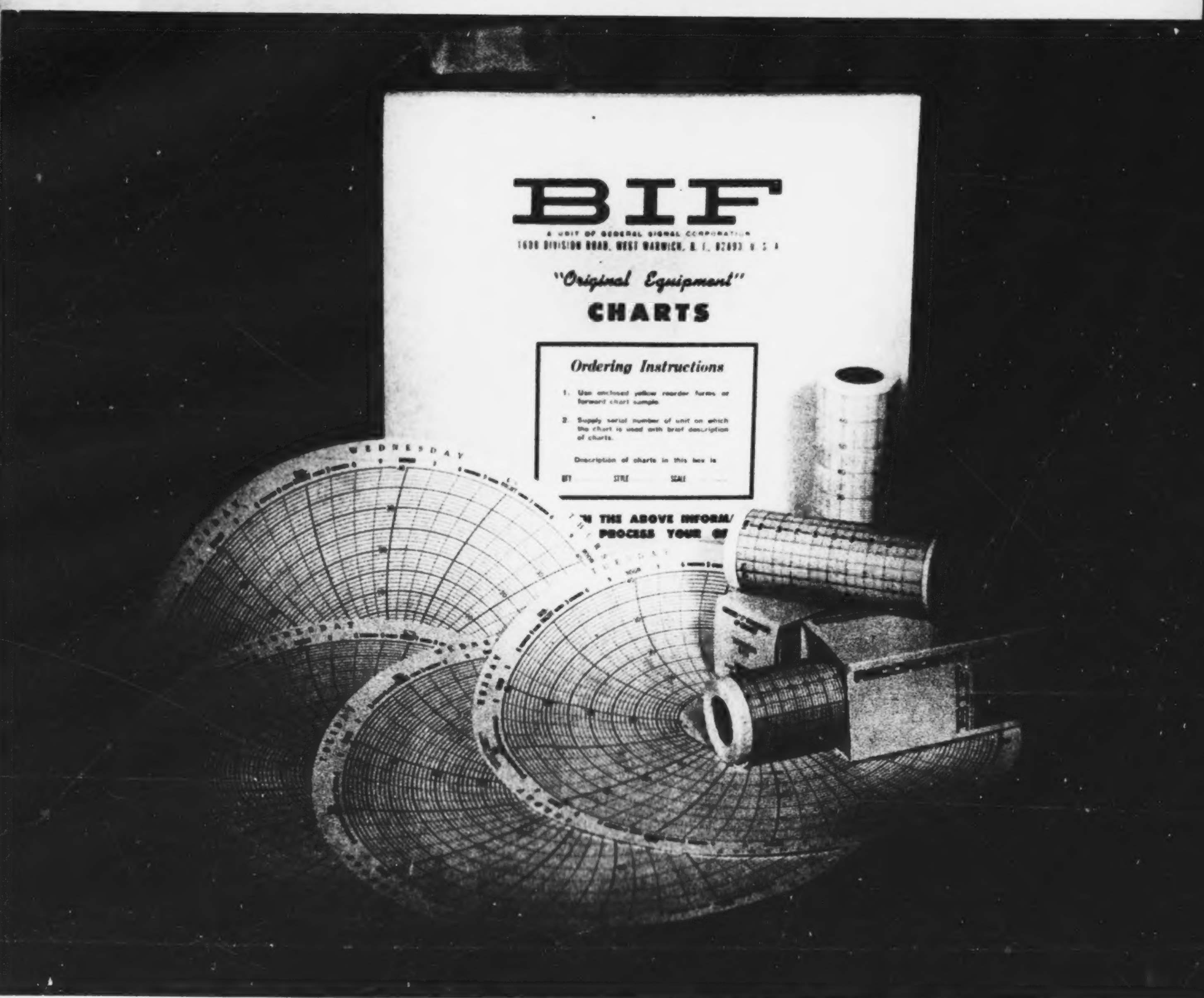

BIF
A UNIT OF GENERAL SIGNAL CORPORATION
1600 DIVISION ROAD, WEST WARWICK, R. I. 02893 U. S. A.
"Original Equipment"
CHARTS
Ordering Instructions
1. Use enclosed yellow reorder forms or forward chart sample.
2. Supply serial number of unit on which the chart is used with brief description of charts.
Description of charts in this box is
QTY STYLE SCALE
THE ABOVE INFORM
PROCESS YOUR OR
WEDNESDAY

Fig. 8.32 Circular and strip charts

(Permission of BIF, a Unit of General Signal)

DISCUSSION AND REVIEW QUESTIONS

(Lesson 2 of 4 Lessons)

Chapter 8. INSTRUMENTATION

Please write the answers to these questions in your notebook before continuing with Lesson 3. The problem numbering continues from Lesson 1.

4. How can the depth of water in a wet well be measured or sensed? List as many different types of devices as you can recall.
5. Why are recorders used instead of operators?
6. What is the purpose of a controller or a control system?
7. Why does an operator need to know the rate of inflow to a treatment plant?
8. How does a thermocouple work?
9. Give an example of each of the following types of indicators:
   1. Fixed scale and movable indicator, and
   2. Movable scale and movable indicator.
10. What is the difference between an open and closed loop control system?
11. What is the basic use of an integrator in a treatment plant?

CHAPTER 8. INSTRUMENTATION

(Lesson 3 of 4 Lessons)

8.8 OPERATION

8.80 How Instruments and Controls Affect Plant Operation

So far we have discussed what instruments and controls are supposed to do. Now we will discuss how instruments and controls are used in basic treatment plant operations.

Instrumentation and controls are necessary and often operations are performed automatically because:

1. Time is saved by not having an operator do the job,
2. An operator couldn't do the job.
3. Hiring an operator to do the job would be impractical or too costly,
4. The job can be done better and faster automatically, and
5. An operator would not want to do the job.

The instrumentation and controls in a treatment plant perform a number of small jobs, each simple and repetitious, which would be a nuisance, an annoyance, an inconvenience, a source of errors, or a safety hazard for an operator to perform manually. You must be able to recognize when instruments and controls are not doing their job properly and be able to take command of the situation and do whatever is necessary to make the instrumentation and control systems operate properly. Instruments and controls do not replace operators, but serve as helpers working for the operator.

8.81 Preliminary Treatment

Depending upon the particular design of the treatment plant, the preliminary treatment section could contain instrumentation monitoring and/or controlling the following functions:

1. Influent level (high-low levels),
2. Influent flow (rate),
3. Explosive gas detection (hydrocarbon, LEL),
4. Bar screen operation (On-Off),
5. Grit removal (On-Off),
6. Ventilation system (On-Off),
7. Valves and gates (closed, percent open),
8. Sump pump (On-Off),
9. High water alarm, and
10. pH.

In addition to the above list of instruments and controls, some plants may have influent pump controls, specific ion probes, dissolved solids concentration instruments, or special application instruments or controls such as computers. However, they are beyond the scope of this introductory discussion into the interface of treatment plant operations and instruments and controls. More information may be obtained from the material listed in Section 8.10, "Additional Reading."

1. *INFLUENT LEVEL*

Most treatment plants have some type of level detection system in the influent sewer or channel leading to the bar screens. The level detection system may be a simple high or low water alarm system or the level detection system may actually measure the depth of flow. Operators need to know the depth of flow (or rate of flow) into the plant so that the operator can determine how many bar screens or grit channels to put on-line. Abnormally low flows could indicate an obstruction in the influent sewer line or worse yet, failure in the sewer system. A high water alarm could indicate blockage at the bar screens or perhaps only a partially opened valve or gate hindering the downstream flow. In small plants, an increase in level could mean that some large industrial discharger was on-line and that treatment processes would have to be adjusted accordingly.

High or low water level detection may be done with electrical probes connected to visual or audible annunciators (alarms). The alarm level is usually mechanically adjusted up or down as needed.

The water level detection system may be a bubbler tube system translating air pressure requirements into water level or an ultrasonic proximity device sensing water level by reflected sound waves. A simple stilling well containing a float attached to a cable and indicator also may be used.

2. *INFLUENT FLOW*

One of the most important and necessary pieces of information provided by instruments is the rate of flow and total flow in 24 hours.

The rate of flow (GPM or MGD) determines what and how many units of treatment plant facilities must be on-line at any one time. For example, if each of 3 grit channels is designed to handle 30 MGD (113,550 cu m/day) and the flow rate into the plant is 60 MGD (227,100 cu m/day), two grit channels should be in service. If low flows at night amount to 20 MGD (75,700 cu m/day) only one grit channel should be in service. Finally, if during wet weather the flows reach 80 MGD (302,800 cu m/day), all three grit channels should be on-line.

The daily flow is used to calculate the amount (pounds or kilograms) of suspended solids and organics coming into the plant, and in and out of the various unit processes (assuming additional flow metering is not used). For example, in determining the pounds of suspended solids loading on a plant or treatment process we use the formula:

$$\text{Susp. Solids Loading, lbs/day} = \text{Flow, MGD} \times \text{SS Conc., mg/}L \times 8.34 \text{ lbs/gal}$$

The pounds (kilograms) per day of solids coming into the plant or the pounds (kilograms) per day leaving the plant both require a knowledge of the flow rate:

$$\text{Solids Entering Plant, lbs/day} = \text{Flow, MGD} \times \text{SS In, mg/}L \times 8.34 \text{ lbs/gal}$$

$$\text{Solids, Leaving Plant, lbs/day} = \text{Flow, MGD} \times \text{SS Out, mg/}L \times 8.34 \text{ lbs/gal}$$

The same basic calculation is required to determine the BOD (organic) load and removal efficiencies.

Without accurate flow rate information it would be very difficult, if not impossible, to operate a modern treatment plant efficiently. Accurate flow measurements and records usually are required by regulatory agencies and most plants continuously monitor the flow rate on a circular or strip chart. Therefore, it cannot be stressed too strongly that accurate and reliable flow measurements are necessary in order to properly operate a treatment plant.

3. *EXPLOSIVE GAS DETECTION*

Some of the treatment plants that are subject to receiving wastewater which contains spills of gasoline or other petroleum products have installed an explosive or combustible gas detection instrument. This type of instrument is designed to sense the Lower Explosive Limit (LEL) for hydrocarbons mixed in air.

This type of instrument may be portable or permanently installed. Usually it has some type of sampling pump that passes the air sample across a combustible gas detection cell, which activates an alarm when the LEL is approached. In some permanent installations it may actually shut off electric motors or other ignition sources before the LEL is reached.

The major emphasis given to this type of instrumentation is for safety. This instrument may or may not be useful in detecting hydrocarbon concentrations which affect treatment, but it is unquestionably necessary for safety reasons if the treatment plant is subject to explosive gases or vapors.

4. *BAR SCREEN OPERATION*

Instrumentation or control for a bar screen may consist of a simple in or out of service indicator with manual start and stop switches. This is usually accomplished by connecting a panel light to the bar screen rake or conveyor motor so that the light is on when the motor is running and is off when the motor is off or trips-out on overload. A light indicating availability of power also may be provided. An alarm (usually audible) may be sounded if the bar screen motor trips-out. Another indication of bar screen difficulties would be the rising water level ahead of any plugged bar screen, and subsequently a high water level alarm will sound.

The bar screens are one of the most important pieces of equipment in a treatment plant since all of the plant flow usually must pass through the bar screen. Any plugging or obstruction of the screen usually will result in a lowered water level downstream and an increased water level upstream. If the problem is not immediately resolved, flooding may occur. Although it is possible to bypass the bar screens in many plants, this usually leads to other problems later since rags, trash, and other debris usually caught by the bar screen hang up someplace later in the treatment process.

In most cases the number of bar screens on-line is controlled by the plant influent flow. However, in special cases of heavy rag loads or debris loads, additional bar screens may be put on-line. The bar screenings hopper also may have a level alarm detection device for high levels.

5. *GRIT REMOVAL*

The gravity design grit channels are very simple and reliable in operation. The instruments and controls associated with this system may be an indicator showing whether the grit collection drive system and pumps were on or off. Usually some alarm function also is available for motors tripping out on overload.

The grit hoppers also may contain a grit level detection device or a high grit level alarm. The grit level device usually works on the ultrasonic sound wave principle and is similar to the influent water level sensing instruments. The high level alarms may be electric probes, optical sensors or ultrasonic sound wave instruments.

Usually, aerated grit removal systems would also feature instrumentation to indicate and to control the amount of air being used, and an alarm to indicate high air pressure or loss of air. High air pressure would usually indicate plugging of the grit aerators and loss of air or low pressure would indicate leakage or low water level in the grit tank.

In most plants the number of grit tanks in service is a function of flow and is manually controlled by the operator.

6. *VENTILATION SYSTEM*

Most preliminary treatment ventilation systems consist of single-stage fans or blowers evacuating foul air to the activated sludge process, an odor removal system or direct to the atmosphere. In most cases an indicator light shows which fans are on-off and if power is available to the fans. Alarms indicating motor trip out also may be provided.

A manometer or other low pressure gage also may be used to show the air pressure in the air duct. This is one means of determining whether the proper amount of foul air is actually being removed. As an example, the fan motor may be running but failure of the vee belts to the fan would result in no air transport.

The ventilation system must be kept operating both for the operator's safety and for minimizing the accumulation of concentrations of moist or otherwise corrosive and toxic gases.

7. *VALVES AND GATES*

Motor-operated gates and valves are usually monitored to indicate whether they are opened, closed, or percent open and if power (air or electrical) is available to the motor operator. The valves and gates also may be remotely opened or closed in many cases, as well as being controlled locally.

Gates and valves control the flow of wastewater in a treatment plant and their proper operation is absolutely essential to efficient treatment plant operations. Motor-controlled gates may be used ahead of bar screens and grit tanks. They also usually feature limit switches that cut the power off to the motor operators when a gate reaches the top or bottom of its travel. Without this provision, the gates or valves are likely to jam themselves open or closed or, worse yet, some structural failure of the system could result. Large butterfly valves can be modulated (partially opened or closed) to keep a constant flow rate to one battery (portion of a treatment process such as one clarifier) of the plant and the remaining flow would be diverted to another battery.

8. *SUMP PUMP*

Usually a sump pump has indicators showing power availability and whether it is on or off. However, in some cases a level sensing and control system will turn on a second set of pumps if the flow is greater than that which can be handled by one pump.

A common system could incorporate the use of a float connected to a switch. When water enters the sump, it raises the float which trips a switch starting the sump pump motor. After the pump dewaters the sump, the float drops tripping the switch and turning the pump off.

9. *HIGH WATER ALARM*

In basements or pipe galleries, high water alarm probes are usually installed to alarm any possible flooding conditions that may occur. The devices are usually electrical probes that short out when touched by water and ring an audible alarm.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.8A List as many functions in the preliminary treatment section as you can recall that could contain instrumentation.

8.8B Why does an operator need to know the influent level to a plant?

8.8C How can gasoline or other petroleum products be detected in a wet well?

8.8D Why should wet well ventilation systems be kept operating continuously?

8.82 Primary Treatment

Primary treatment usually consists of gravity sedimentation tanks with facilities (flights) to scrape the settled organic solids into a sludge hopper or sump; facilities to move floatable materials into grease or scum troughs or boxes; and weirs to control the flow of the clarified effluent.

Usually an operator would be concerned with the following instrumented activities in primary treatment:

1. Collector drive motor, ON-OFF — Power Available,
2. Flights, running — stopped,
3. Grease skimmers, ON-OFF — Power Available,
4. Primary sludge blanket depth, feet or inches (meters or centimeters),
5. Primary sludge pumps, ON-OFF — Power Available,
6. Primary sludge draw-off valve, OPEN-CLOSED — % Open,
7. Primary sludge flow (gpm or *L*/sec),
8. High water alarm, Audible — Visible, and
9. Water level control valve, Closed — % Open.

Some treatment plants may have additional facilities which are instrumented, such as primary influent or effluent channel aeration, secondary treatment flow diversion or control systems, temperature probes, and others depending upon the specific situation.

1. *COLLECTOR DRIVE MOTOR*

Depending upon the location of the power control panel and the operations control room, the drive motors usually have colored lights indicating that power is available, and whether the motor is "ON" or "OFF". The motors usually have "local" (on-site) on and off switches, circuit breaker switches at the electrical power panel, and in addition may have control switches in the central control room.

2. *FLIGHTS*

A flight movement-detection system is used to ensure that sludge is being continuously moved. In some instances the collector chain may fail and scraping of the primary (raw) sludge to the discharge point would cease even though the collector drive motor would still be operating.

Unless flight movement failure is promptly detected and the primary tank is taken out of service, dewatered and washed down, serious odor problems could result as well as transfer of septic wastes to the secondary treatment system, which would negatively affect the process. The actual flight movement detection system may be as simple as a pivoted stick which moves everytime a flight strikes it. A more sophisticated flight detection system uses a proximity device which sends out an ultrasonic signal which is reflected everytime the flight passes by. An alarm signal would be generated if a signal is not reflected back after a specified time delay.

3. *GREASE SKIMMERS*

Grease skimmers are usually rotating blades driven by an electric motor. Their function is to scrape and push floatables (grease-oils) into a trough for transport to further treatment. In most cases the grease skimming operation is relatively simple and reliable. Complexity of the skimming operation depends on the amount of floatables being removed in the primary tank. The skimmers may be operated continuously or only once a shift depending upon the load of scum and floatables.

The controls for the grease skimmer drive motors are similar to those used for flight collector drive motors. There are usually colored indicator lights showing power available and whether the units are on or off. The drives may be turned on and off locally, or remotely in the central control room. In some installations, a timer may be incorporated into the skimmer drive control to regulate the amount of time the skimmers operate each period.

4. *PRIMARY SLUDGE BLANKET DEPTH*

One of the important measurements in the operation of primary sedimentation tanks is the primary sludge blanket level. Unless the proper level is maintained by controlling the removal of sludge from the tanks, two situations could occur. One problem develops when high blankets and poor suspended solids and BOD removal efficiencies occur in the primary tanks. The other is the removal of dilute sludge or, in the worst case, primary wastewater instead of sludge from the sludge hopper.

Sludge blanket depths may be manually measured by using a hose and an aspirator. This is done by lowering the hose into the tank until sludge comes out of the aspirator and then measuring the length of hose used.

Another method of measuring blanket depths uses two ultrasonic transmitters and receivers (probes), one for low level and one for high level. The height of the low and high level probes are mechanically set at the desired minimum and maximum blanket levels. Whenever the sludge blanket level drops below the desired minimum, a signal is generated which may turn on an indicator light, alarm or turn off the sludge pump. Conversely, when the sludge blanket level exceeds the maximum desired level, another indicator light or alarm may come on or the sludge pump may be turned on depending upon the specific design.

The probes operate on the principle that the denser sludge mixture attenuates (decreases) the signal level between the ultrasonic transmitter and receiver more than that which would occur due to wastewater alone. The changes in signal level correspond to the sludge blanket density. Under these circumstances, the lower probe should always indicate an attenuated (decreased or diminished) signal and the upper probe should indicate an unattenuated (undiminished) signal.

5. *PRIMARY SLUDGE PUMPS*

One of the most important and critical operations in the primary treatment system is the proper operation of the primary sludge pumps. Under-pumping can result in high sludge blankets and poor removal efficiencies in the primary tanks. When this happens the suspended solids and BOD capture efficiencies could be adversely affected. Under the worst circumstances, when a pump does not work, a situation similar to that of inoperative flights caused by a broken collector chain would result. These circumstances could produce odors and septic wastes.

Over-pumping, on the other hand, can send very dilute primary sludge to the anaerobic digesters and cause problems in digester operation by reducing the hydraulic detention time and temperature and also by wasting energy by unnecessary pumping.

Again the basic controls for the pump motors would consist of colored lights to indicate power availability, and whether the motor was on or off. The control switches are usually located next to the pumps and also may be duplicated in the central control room.

The amount of pumping can be regulated by manually turning the pumps on and off, by using a timer control to turn the pumps on and off for a given number of minutes each hour in sequence or by using a signal from a sludge density meter control to turn the pumps off after the pumps have been turned on manually or by timer sequence.

6. *PRIMARY SLUDGE DRAW-OFF VALVES*

In some treatment plants, primary sludge is removed from the tanks by a *HYDROSTATIC SYSTEM*[5] (gravity) instead of using pumps. In these installations the controls usually operate a motorized valve. Indicator lights usually show whether a valve is open or closed. In addition, there may be an indicator (meter) located in the control showing what percent the valve is open with a switch to power the valve open or closed. A mechanical indicator is usually attached to the valve itself to indicate the valve position.

A timer system also may be incorporated to open each valve a predetermined amount for a set number of minutes each hour.

A sludge density meter also may be used to control the closing of each draw-off valve. In this case when the primary sludge density drops below a pre-set limit, for example four percent, a signal is generated closing that particular valve and opening the valve in the next tank. This process is continuously repeated.

7. *PRIMARY SLUDGE FLOW AND PRESSURE*

Most treatment plants carefully meter the amount of primary sludge that is withdrawn and sent to the anaerobic digestion system. The amount of flow per day is used to compute the volatile solids quantity and distribution to the digesters. Improper metering could result in shock overloads to the digester which could upset the process. The percent solids of the primary sludge and its volatile solids content are usually analyzed in the laboratory. However, a sludge density meter may be used to determine the percent solids concentration and a historically valid number for the percent volatile solids may be used in the calculations:

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[5] *Hydrostatic System. In a hydrostatic sludge removal system, the surface of the water in the clarifier is higher than the surface of the water in the sludge well or hopper. This difference in pressure head forces sludge from the bottom of the clarifier to flow through pipes to the sludge well or hopper.*

$$\begin{array}{l}\text{Digester}\\ \text{Loading,}\\ \text{lbs VS/day}\end{array} = \text{Prim Sl, }\frac{\text{gal}}{\text{day}} \times \frac{8.34\text{ lbs}}{\text{gal}} \times \frac{\text{Tot Sol, \%}}{100\%} \times \frac{\text{Vol Sol, \%}}{100\%}$$

or

$$\begin{array}{l}\text{Digester}\\ \text{Loading,}\\ \text{kg VS/day}\end{array} = \text{Prim Sl, }\frac{\text{liters}}{\text{day}} \times \frac{1\text{ kg}}{1\ L} \times \frac{\text{Tot Sol, \%}}{100\%} \times \frac{\text{Vol Sol, \%}}{100\%}$$

The primary sludge flow is usually metered by a Venturi meter, or a magnetic flow meter, although other closed-conduit metering devices may be used. The signal from the flowmeter is usually transmitted to a read out device (meter) and flow recorder (circular or strip chart). An integrator is usually included to determine the total sludge flow per day. The flow readings may be indicated locally or in the central control room.

Besides knowing the flow rate and total flow, the operator also is interested in the primary sludge line pressure. Higher than normal pressure readings usually indicate a possible obstruction in the line or that the line is due for routine cleaning. In most cases, a pressure gage is mounted directly on the line; however, a pressure transducer may be used to transmit a signal to a remote indicator in the central control room.

8. *HIGH WATER ALARM*

A high water alarm system is usually incorporated into the primary treatment system to indicate potential or possible flooding. The alarm systems are usually identical throughout the plant and they are discussed in the preliminary treatment section.

9. *WATER LEVEL CONTROL VALVE*

Modulating (regulating or adjusting) butterfly valves are used in some plants to control the flow into each primary tank in an attempt to equalize the flow and water level in each tank. This will promote the most efficient use of the tanks in service. When some tanks get more flow, their suspended solids and BOD capture efficiencies usually drop and cause an overall decrease in treatment efficiency.

The actual operation of a level control system usually incorporates some type of level detection device (probes or proximity device) which transmits a signal to a motorized valve. The water level signal and percent opening of the valve are calibrated together to obtain the desired water level in each tank. If the water level is dropping, the valve would open more and if the water level is rising, the valve would close. The percent open of each valve is usually read at the motorized valve operator and in most cases should change with the change in flow.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.8E List the instrumented activities that could concern an operator in primary treatment.

8.8F How can movement of flights be detected?

8.8G How can sludge pumps be controlled or regulated?

8.8H Why are butterfly valves used in some plants to control the flow to each primary tank?

END OF LESSON 3 OF 4 LESSONS ON INSTRUMENTATION

Please answer the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 3 of 4 Lessons)

Chapter 8. INSTRUMENTATION

Please write the answers to these questions in your notebook before continuing with Lesson 4. The problem numbering continues from Lesson 2.

12. Why are operations performed automatically by instrumentation and controls?
13. Why are accurate flow measurements and records important?
14. How would you determine if a wet well ventilation system was working?
15. What problems can develop if an improper sludge blanket depth is maintained in a primary clarifier?

CHAPTER 8. INSTRUMENTATION

(Lesson 4 of 4 Lessons)

8.83 Activated Sludge Process

After primary treatment, wastewater can be further purified by secondary treatment. One of the common forms of biological secondary treatment is the activated sludge process. In this process, dissolved and colloidal organic wastes not removed by primary treatment are broken down and stabilized by bacteria in the presence of air.

In the activated sludge process, primary effluent is gently mixed into a biological culture (mixed liquor suspended solids or MLSS) by air diffusion in the aeration tank. After a period of time, the mixture (MLSS) is sent to the secondary clarifiers where the biological floc settles out. Part of the settled biological floc (return activated sludge or RAS) is returned to the aeration tank and the excess biological floc (waste activated sludge or WAS) is sent to the head of the primary sedimentation tanks or to some other alternative sludge treatment process. In order for the process to function properly and efficiently, the operator must carefully control (balance) the amounts of organic waste, biological floc, and air in the aeration tanks. Since the operator usually has little or no control over the amount of organic waste coming into the aeration tank, the operator can only control (balance) the amount of biological mass (MLSS) and air used.

Usually, an operator would be concerned with the following instrumented activities in the aeration part of the process:

1. Primary effluent flow (MGD or cu m/day);
2. Aeration air rate (cfm or cu m/sec);
3. Aeration air pressure (psi or kg/sq cm);
4. Air compressor — ON-OFF, Power Available, Temperature (°F or °C) of Air and Oil, Speed (rpm), % Vane Opening, Oil Level, Oil Pressure and Blower Vibration;
5. Mixed liquor suspended solids (mg/*L*);
6. Dissolved oxygen concentration in the mixed liquor suspended solids (MLSS) (mg/*L*); and
7. Final sedimentation tanks (Influent Flow, Return Activated Sludge Flow (RAS), and Waste Activated Sludge Flow (WAS).

Other laboratory information is also necessary to operate the activated sludge process, for example, BOD and COD, suspended solids, percent volatile solids, sludge settleability, and sludge volume index (SVI).

1. *PRIMARY EFFLUENT FLOW*

   In many cases the primary effluent inflow is the same as the plant flow, except in cases where only part of the flow receives secondary treatment, where there are process recycle flows, or there are sidestreams such as cooling water flows. Flow rate and 24-hour total flow are usually measured in terms of million gallons per day (cu m/day). Accurate flow measurements and laboratory data are necessary to determine the organic loading in the aeration system and for information such as the air rate per gallon (cu m) of wastewater treated.

   Flow rates are usually recorded on a circular or strip chart and the total flow is obtained from an integrator or totalizer. The flow sensing, indicating and recording devices have been previously discussed as part of preliminary treatment instrumentation.

2. *AERATION AIR RATE*

   The aeration air flow rate is usually measured in terms of cubic feet per minute (cfm) or cubic meters per second (cu m/sec). The air flow rate may be measured at each air compressor or be read as a total from the main air header, usually by a differential pressure metering device such as an orifice plate.

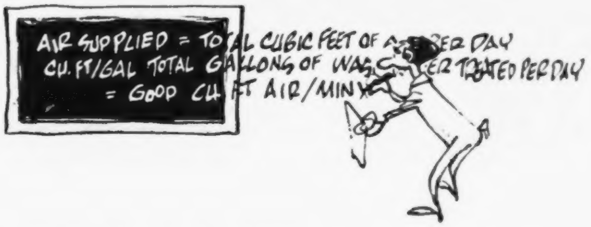
Accurate air flow measurements are very important because oxygen (air) is one of the basic components in the activated sludge process. Insufficient or under-aeration process air will usually result in under-treatment and poor effluent quality; while excess or over-aeration will waste energy and unnecessarily stress and wear the air compression system.

In most conventional activated sludge treatment plants, air is supplied at the rate of 1 to 2 cubic feet of air per gallon (0.13 to 0.26 cu m of air per cu m) of wastewater being treated. For example, in a 5 MGD plant the air rate may be 6,000 cfm (2.8 cu m/sec). To determine the air rate per gallon of wastewater treated, perform the following calculation:

$$\begin{aligned}\text{Air Supplied, cu ft/gal} &= \frac{\text{Total Cubic Feet of Air per Day}}{\text{Total Gallons of Wastewater Treated per Day}}\\ &= \frac{6000 \text{ cu ft air/min} \times 1440 \text{ min/day}}{5{,}000{,}000 \text{ gallons wastewater/day}}\\ &= 1.728 \text{ cu ft air/gallon treated}\end{aligned}$$

or

$$\begin{aligned}\text{Air Supplied, } \frac{\text{cu m air}}{\text{cu m water}} &= \frac{\text{Total Cubic Meters of Air per Day}}{\text{Total Cubic Meters of Wastewater Treated per Day}}\\ &= \frac{2.8 \text{ cu m/sec} \times 60 \text{ sec/min} \times 1440 \text{ min/day}}{19{,}000 \text{ cu m/day}}\\ &= 12.7 \text{ cu m air/cu m water}\end{aligned}$$


AIR SUPPLIED = TOTAL CUBIC FEET OF A ER DAY
CU. FT/GAL TOTAL GALLONS OF WAS ER TREATED PER DAY
= GOOD CU FT AIR/MIN

3. *AERATION AIR PRESSURE*

Besides the air flow rate, another important measurement is air pressure. Abnormally high or low air pressures usually indicate clogged air diffusion devices or air leaks.

Pressure gages are usually placed at the air compressors and also downstream at main aeration lines. A difference in pressure between the two points would indicate head losses (pressure losses) due to partially closed valves or other restrictions, such as before and after air filters.

Most aeration systems operate at about 7 psig (0.5 kg/sq cm) to overcome the static head on submerged diffusers. Bourdon tube pressure gages are commonly used to measure pressure directly. The read-out of pressure is usually transmitted and also displayed in the control room by use of pressure transducers. Unlike air flow, air pressure is usually fairly constant and usually is not automatically recorded.

4. *AIR COMPRESSOR: ON-OFF, POWER AVAILABLE, TEMPERATURE (AIR AND COMPRESSOR OIL), SPEED, % VANE OPEN, VIBRATION, RUNNING HOURS, OIL LEVEL, AND OIL PRESSURE*

Besides the air flow, pressure and temperature, it is necessary to know other facts about the air generation system.

In multi-air compressor systems, a read-out (from either TV screen (CRT) or computer print-out) is provided to show what compressors are operating and if power is available (for electricity driven compressors) or the status of other fuel supply systems (for example, how much diesel fuel is in the storage tanks). Available fuel volumes may be measured by a float or other sensing devices which will indicate the amount of fuel remaining. Also, air compressor failure or power failure alarms are usually incorporated into the system. As discussed previously for electrically operated equipment, the ON-OFF indicator lights are wired into the power supply. Liquid fuel volume indicators usually have float or similar types of level indicators that are calibrated to read in terms of gallons (cubic meters) or fractions of tank capacity.

Another important measurement in air compression operation is the temperature of both air and lubrication oil. Excessive compressed air temperatures may indicate an open bypass valve or other possible mechanical malfunctions. Excessive lubrication oil temperatures may indicate motor overload, low oil levels or inoperative oil coolers. High oil temperatures usually trigger alarm circuits and also may automatically shut the compressor off in some installations.

Ambient (surrounding or room level) air and compressed air temperatures may be measured directly by the use of bimetallic thermometers or capillary bulb thermometers in the air stream. However, remote reading thermometers will commonly use some sort of a thermocouple for gas or oil temperature sensing.

Compressor speed in terms of RPM is used by the operator to determine if the proper amount of air flow and pressure is resulting from a given RPM for engine-driven compressors. Most air compressors operate efficiently within given RPM ranges; however, low ranges are very inefficient while high speeds may damage the equipment or cause the motor to overheat.

The RPM is usually measured by a mechanical drive tachometer, electrical generator tachometer, electrical impulse tachometer, or photo electric tachometer. All except the mechanical drive tachometer allows for remote signal transmission and read-out of RPM.

Constant RPM electrically driven air compressors modulate the inlet air vanes to control air discharge output. This information is usually read as percent opening of the inlet vanes.

Some compressors, usually electrically driven, are equipped with vibration sensing devices. These devices are designed to sense displacement, velocity, or acceleration. They are basically a safety device to shut down the compressor and initiate an alarm if the compressor or motor starts to vibrate excessively due to any unbalanced forces or loose floor connections.

Both internal combustion and electrically driven air compressors usually have some sort of Hour-Meter to determine how many hours each unit has operated since the last repair or overhaul. To equalize wear, compressors are usually rotated after so many hours of operation. Also the Hour-Meter can be used to schedule preventive maintenance functions such as oil changes.

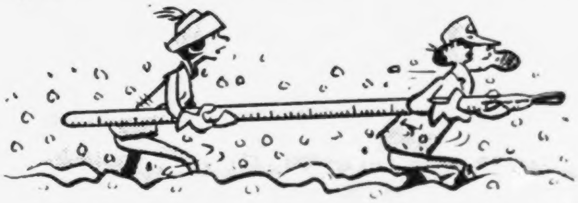
Most Hour-Meters are a form of electric clock that registers the number of hours on a totalizer. The hours of running time may be indicated at the compressor control panel and/or remotely indicated in a central control room.

Electrically driven compressors also usually have an ammeter read-out for indicating power consumption. The ammeter also may be set to signal an alarm and/or shut off the compressor when it is overloaded.

Another important measurement is that of oil level. The measurement may be manually performed by a dip stick, read from a sight glass, or by use of other level sensing devices (electronic or ultrasonic systems) which may initiate alarms if the oil level is too high or too low.

5. *TEMPERATURE OF MIXED LIQUOR SUSPENDED SOLIDS (MLSS)*

Temperature changes greatly influence all biological processes. You must carefully monitor the temperature of the mixed liquor in the activated sludge process. The biological metabolism rate (activity) increases with temperature increases and decreases with decreasing temperature. Consequently, more biological mass is required during cooler temperatures to obtain the same degree of treatment. Therefore, you must increase the MLSS concentration during the cooler months and decrease it during the warmer months in accordance with the particular conditions at the plant.



The temperature readings may be taken and recorded manually or they may be continously monitored and recorded on a chart. The temperature may be sensed by any of the previously described temperature sensing devices.

6. *DISSOLVED OXYGEN CONCENTRATION*

In some activated sludge plants, dissolved oxygen (DO) meters are provided to monitor the level of dissolved oxygen in the aeration mixed liquor suspended solids.

The oxygen level in mg/*L* is monitored to ensure that adequate oxygen (air) is being provided in the aeration tanks. A dissolved oxygen level of 1 to 4 mg/*L* is usually maintained in the aerators, depending upon the particular requirements of the given activated sludge process.

The oxygen level is measured by a probe and meter. The probe may be portable or permanently installed in the aerator. Single or multi-probes may be installed in one or more aerators. At the present state of development, most DO meters are basically lab instruments and should be treated with care. The probes require frequent cleaning and the meters should be calibrated routinely to ensure their accuracy.

In some plants the output from the DO meters controls the aeration blowers (compressors) thereby theoretically optimizing the air flow rate to the biological culture in the aeration tanks. Remote oxygen level read-outs are usually indicated and recorded along with the corresponding air rates.

7. The instrumentation and control of the final secondary sedimentation tanks are very similar to the primary sedimentation tanks. For all practical purposes, the following operations are identical:

   a. Collector drive motor,
   b. Sludge blanket depth,
   c. Sludge pumps,
   d. Sludge draw-off valves, and
   e. High water alarm.

The operation of the sludge pumps for return activated sludge (RAS) and metering may vary slightly from primary sludge pumping and metering since usually only part of the flow (25 percent up to 100 percent) is returned to the aeration tank; the remaining waste activated sludge (WAS) is usually routed back to the head of the primary tanks or to some other sludge handling process.

Consequently, the total RAS flow and WAS flow may be metered or the RAS flow to the aeration tanks and the WAS flow may be monitored. In either case, it is important to have accurate measurements of RAS and WAS flows to calculate the return rate, and the Mean Cell Residence Time (MCRT).

A turbidimeter is used in some plants to monitor the effluent quality from the secondary sedimentation tanks. In on-line turbidimeters, a pump directs a small stream of final effluent across a light beam. The scattering or attenuation of the light beam due to particles in the effluent is measured and indicated in turbidity units. The turbidity may be continuously monitored or measured from grab samples analyzed in the lab. The process used is commonly dictated by the legal monitoring requirements specified in the NPDES permit for the plant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.8I How is air flow measured?

8.8J Where are air pressure gages usually placed in the aeration system of the activated sludge process?

8.8K How are oil levels in air compressors measured?

8.84 Anaerobic Sludge Digestion

The settled organic solids from the primary sedimentation tanks and the waste activated sludge from secondary treatment require further processing. One common method of processing and treating the sludge is "anaerobic sludge digestion." Under ideal environmental conditions, anaerobic bacteria stabilize and convert most of the organic matter into methane gas, carbon dioxide gas and water. In this airless process, you must carefully control the amount and rate of sludge feeding to the digester, the operating temperature of the digester, and the rate of change of temperature. Excessive organic loadings or temperature changes adversely affect the anaerobic bacteria and can cause an upset of the biological treatment process.

The following activities are usually instrumented or controlled:

1. Raw sludge feed controller,
2. Digester tank level and alarms,
3. Digester sludge flow,
4. Digester gas flow,
5. Digester gas pressure,
6. Digester sludge temperature,
7. Digester heating system (steam, hot water),
8. Digester transfer and recirculation pumps,
9. Digester gas quality,
10. Combustible gas alarm, and
11. Digester gas mixing compressor.

1. *RAW SLUDGE FEED CONTROL*

Feeding the digester(s) with primary sludge may be a relatively simple operation in small primary treatment plants with only one or two digesters. In these situations the primary sludge is intermittently fed to the digester whenever the sludge pumps are activated. The sludge solids and volatile solids concentrations are analyzed in the laboratory. The flow may be metered or estimated from the pump curves and time of pump operation. Loadings are calculated on the basis of solids concentrations and flows. In all systems the pumping is either controlled by the sludge blanket depth or sludge concentration.

However, in larger plants with many primary tanks and digesters, more sophisticated controls are necessary since large volumes of primary sludge must be continuously distributed to many digesters. In addition, not all digesters are loaded at the same rate since individual digesters may have varying operating capacities. For example, a modern, clean, heated, and gas-mixed digester may be loaded between 0.1 and 0.2 pounds of volatile solids per day per cubic foot (1 and 2 kg VS/day/cu m) of digester capacity. Uncleaned, unmixed digesters may be able to handle only 0.05 lbs VS/day/cu ft (0.5 kg VS/day/cu m). Consequently, a well operating and closely controlled primary sludge feed system is essential.

As an example, a primary sludge feed system would pump all of the primary sludge to one battery (row) of digesters for a set period of time or for a set volume such as so many gallons (cubic meters). In either case, the calculations would be based on the pounds (kilograms) of volatile solids pumped during that time period to that battery. Next, each digester in that battery would be fed the desired amount of sludge (pounds or kilograms of volatile solids) controlled by the amount of time a valve to that digester was open, the percentage opening of the valve, or the gallons (cubic meters or liters) of sludge metered into that particular digester. The gallons (cubic meters or liters) of sludge metered in the last case may be monitored by a flow meter or by the change in digester tank level. Therefore, in its most basic form, much of the control is done manually by the operator. In the most automated form, the control is performed by *SOFTWARE PROGRAMMING*[6] from a computer. In most cases, each battery of digesters is loaded in sequence or by level priority continually around the clock.

Ideally, the control system would permit continuous loading of all digesters in proportion to the pounds of volatile solids being sent to the digestion system. Such a system would proportion a part of the total primary sludge flow to each digester by having a flow meter and automatic control valve at each digester. In addition, the digested sludge flow withdrawal rate would also be automatically controlled to maintain a set or desired level in the digester. In order to obtain this level of control, a process control computer would be necessary and discussion of such a system is beyond the scope of this chapter.

2. *DIGESTER TANK LEVEL AND ALARMS*

Almost all digester tanks have some means of determining their liquid level. Some of the older digesters use simple overflow pipes. An example is the opening of an overflow pipe at the desired digester level and pumping primary sludge into the digester until digested sludge overflows from the pipe. Other systems use a variable-level swing overflow pipe in which the discharge level of the pipe is raised or lowered to the desired level and primary sludge coming into the digester automatically displaces or forces digested sludge out of the overflow.

These examples obviously require the operator to be at the digester to determine or change the level. Other level control systems may use a pressure transducer calibrated to translate liquid hydrostatic pressure into feet (meters) of sludge in the digester. The tank level may be indicated and recorded in the control room from where it would also be possible to raise or lower the level by operating powered remote control valves.

In addition to digester tank levels, most systems use some type of high or low level alarm. The alarms may be triggered by any of the previously discussed level sensing instruments or software sensing devices which detect when levels are too low or too high. A low level alarm could indicate that a digested sludge valve was accidently left open, a possible control system malfunction, or a possible leak or break somewhere in the system. A high level alarm could indicate plugging of the overflow, a control system malfunction, or an inoperative digested sludge withdrawal system.

3. *DIGESTED SLUDGE FLOW*

The digested sludge is not metered in some plants because the operators assume that digested sludge flow equals the primary sludge flow. For small plants with one or two digesters, this assumption is probably acceptable. However, in large plants with large capacities it is important to know the digested sludge flow pattern. This permits monitoring of the rate and frequency of withdrawal and provides a verification of the primary sludge flow. Flows may be monitored from each tank, battery of digesters, or total digested flow.

Venturi meters or magnetic flow meters are commonly used to measure the digested sludge flows. Flow data are usually recorded, especially in situations where the digested sludge receives additional treatment, such as dewatering or chemical conditioning. The flow rate and total flow are usually recorded at the control room.

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[6] *Software Programs. Computer programs designed and written to monitor and control wastewater treatment processes or other processes.*

4. *DIGESTER GAS FLOW*

Gas production from each digester is monitored daily. This information is used to analyze the volume of gas production per pound (gram or kilogram) of volatile solids added and destroyed. Gas production is also a strong indicator of digester performance with low gas production usually indicating some type of problem.

Since digester gas pressure is relatively low, about 8 to 12 inches (20 to 30 cm) of water, metering systems with very low head losses must be used. Also, the meters must operate over a fairly wide range of gas flows. Positive displacement meters and turbine meters are commonly used to measure gas flows. The total gas production may be manually determined from daily mechanical integrator readings of the gas production rate, or it can be automatically monitored continuously and recorded in the control room.

5. *DIGESTER GAS PRESSURE*

Digester gas pressure must be monitored to ensure that the safety valves are operating properly (fixed cover digesters). Although the gas pressure is relatively low, usually 8 to 12 inches (20 to 30 cm) of water, higher pressures may seriously over pressure the digesters and a low pressure may indicate gas leakage from the system.

The gas pressures in many digesters are monitored by the use of water-filled manometers. Since the gas pressure is relatively constant, it is usually not automatically monitored and recorded, but visually checked by an operator during every shift.

6. *DIGESTER SLUDGE TEMPERATURE*

One of the most important operating controls is digester temperature. To achieve efficient digestion, the temperature should be maintained near 95°F or 35°C (mesophilic operations). Therefore, nearly every digester has some type of built-in temperature sensing device. Thermocouples are commonly used with remote readings in the control room. Temperatures are usually continuously recorded on a circular chart. Manual temperature readings may be made by placing a thermometer in sludge running into the sample sink.

7. *DIGESTER HEATING SYSTEM*

Assuming that the digesters are heated either by direct steam injection, steam eductors, or by steam-heated exchangers, some means of indicating the rate of steam flow and the total pounds of steam used per day is necessary. Usually, steam pressure is also monitored. Steam to each digester is usually controlled by remotely controlled steam valves. The percent opening and length of time each valve is opened is determined by the temperature in the digester. A fully automated digester heating system would use a process controller to sense the difference between the existing digester temperature and the set point temperature and route steam (heat) according to the needs of each digester. This process controller would also control the steam production of the steam boiler to match the digester heating needs.

8. *DIGESTER TRANSFER AND RECIRCULATION PUMPS*

Transfer and recirculation pumps are an important part of anaerobic sludge digestion operation. The pumps are used to mix the digester contents, transfer sludge between digesters, pump out digested sludge and pump supernatant out of digesters. Several pumps are usually interconnected to maximize flexibility of operations.

The instrumentation and control of the transfer or recirculation pumps are very similar to primary sludge and return activated sludge pumping operations.

9. *DIGESTER GAS QUALITY*

In some plants, automatic means of analyzing digester gas quality is provided. Either the carbon dioxide (CO_2) or methane (CH_4) gas content is analyzed and the read-out is usually given in percent carbon dioxide or methane.

The percent of carbon dioxide or methane in digester gas is usually a good indicator of the status of the biological process. Digestion gas usually contains 60 to 70 percent methane and the remainder is considered to be carbon dioxide gas. Upset digesters tend to have a much lower percentage of methane gas and a higher percentage of carbon dioxide gas, for example, 40 to 50 percent CH_4 and 50 to 60 percent CO_2.

The digester gas quality can be measured at the digester itself or a small side stream of digester gas may be pumped to the analyzer from the digester or the main gas line. In most cases, digester gas tends to be saturated with moisture and some type of moisture trap or drier is necessary to protect the analyzer. Also, some digester gases tend to have significant amounts of corrosive hydrogen sulfide (H_2S) gas and a means of absorbing the H_2S also may be necessary.

A gas chromatograph may be used to perform the gas analysis. Instruments like the gas chromatograph and spectrophotometers are basically laboratory instruments and require significant skill and knowledge to operate and maintain them.

10. *COMBUSTIBLE GAS ALARM*

In plants where there are tunnels or other confined spaces, a combustible gas alarm may be provided. This instrument is essentially identical to the explosive gas detection instrument described in the preliminary treatment section. This device is calibrated to activate an alarm at a set Lower Explosive Limit (LEL). If the tunnels or other spaces being monitored do not have a good ventilation pattern in which to place the detector, a sample pump may be built in to pass air over or through the detection device. The purpose of the instrument is to detect any explosive gas leaks or to detect the generation of explosive gases in confined spaces for the safety of the plant and operators.

11. *DIGESTER GAS MIXING COMPRESSOR*

In most modern treatment plants, some form of digester gas mixing is usually provided. Gas mixing is one of the more popular means of mixing the digester. Digester gas compression is similar to aeration air compression with the following differences: (1) the volume is much less, (2) the pressure is usually higher, (3) digester gas tends to be saturated with moisture and contain particulate impurities, and (4) for higher pressure, reciprocating compressors may be used instead of centrifugal or rotary vane types.

As a rule, the gas mixing volume and pressure remain constant and consequently the load on the compressor and its driver also remain constant. Depending upon the design, individual compressors may be provided for each digester, or several manifolded together. In either case ON-OFF, power availability, flow, pressure, and alarm functions are usually provided.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.8L List the activities that are usually instrumented or controlled in the anaerobic sludge digestion process.

8.8M Under what circumstances would digested sludge flow be recorded?

8.8N How are temperatures measured in an anaerobic sludge digester?

8.8O What is the purpose of digester transfer and recirculation pumps?

8.9 ROUTINE MAINTENANCE AND TROUBLESHOOTING

So far we have discussed how instruments and controls work and how they are used in treatment plant process control. Next we will discuss what the operator's role is in maintaining and troubleshooting the instruments and controls. As we have already pointed out, though, unless the operator is qualified, the repair of most types of instruments should be assigned to a specialist in the field. There are many practical and important things an operator can and must do to keep the system operating efficiently.

First, it is important for the operator to recognize that like other equipment in a treatment plant, instruments and controls need attention such as cleaning, adjusting, calibrating, repairing and/or replacement from time to time. In most cases, instruments and controls are more fragile than other pieces of treatment plant equipment and must be given appropriate care whenever handled.

Before we begin routine maintenance or troubleshooting the instruments and controls, it is essential that the operator be familiar with the process and the instrumentation and/or controls used to control the process. If you don't know what you're doing, leave it alone and request assistance!

A routine maintenance program will minimize instrument and control failures. The routine maintenance program should be a written, prescribed procedure defining what the operator is responsible for and what the instrument specialist is responsible for and who will do what and when. Each plant with its different processes, instruments, controls and people will have a unique routine maintenance program. The maintenance program should provide for a file on each instrument and control system. Date of purchase, date of installation, installer, make, and model-serial numbers should all be recorded, along with any maintenance manual, or technical specifications supplied with the equipment. Provisions for on-the-job and off-the-job training should be sought whenever possible.

Based on the manufacturers' recommendations and plant experience, spare parts, plus any special tools should be purchased ahead of time and properly stored. Whenever possible, appropriate areas for instrument maintenance and storage should be dedicated for this purpose; areas with high humidity and corrosive gases are to be avoided.

Before troubleshooting for instrument and control failures, the operator must make certain that the difficulty is truly due to defective instrumentation or control and not due to some quirk in operations. There have been cases where so-called instrument failures have been traced back to simple things like unplugged power supplies, the pneumatic air receiver left out of service after being drained of water and similar types of minor problems.

Before starting work on the system, safety precautions must be observed, such as unplugging electrically connected instruments and controls. Even though they may be low voltage, there is always the possibility of shock to the operator and/or damage to the equipment. Also, care must be exercised when handling toxic materials such as mercury or flammable material such as alcohol which could be encountered when working with manometers. Care also must be exercised with certain types of density meters that use a radioactive cell which by law can only be handled by an appropriately licensed technician. Such devices are required to be identified and labeled accordingly.

Additional precautions must be observed whenever you intend to work on or remove instruments and controls directly attached to live or operating processes. For example, before you remove a pressure gage from an air or water line, be sure that the service has been turned off. Before you turn the service off, be sure it will not adversely affect the system or someone else.

In other words, be sure that others are advised of your intended scope of work. They must be notified or warned of what you are going to do, when you are going to do it, how long it will take, and what will be affected. Therefore, just like any other piece of plant equipment, instruments and controls being worked on should be "tagged-out". This will advise others that the instruments and controls are out of service and must not be used.

The "tagged-out" instruments and controls (Fig. 8.33) must also be "logged" in the shift or daily operations log book. You must note alarm functions that are out of service, so that other means may be used to detect out-of-limit conditions. The use of "Good Communications" and "Common Sense" will avoid a lot of unnecessary "Headaches."

Table 8.2 contains some guidelines on what maintenance and trouble-shooting duties an operator can generally perform.

OUT OF ORDER

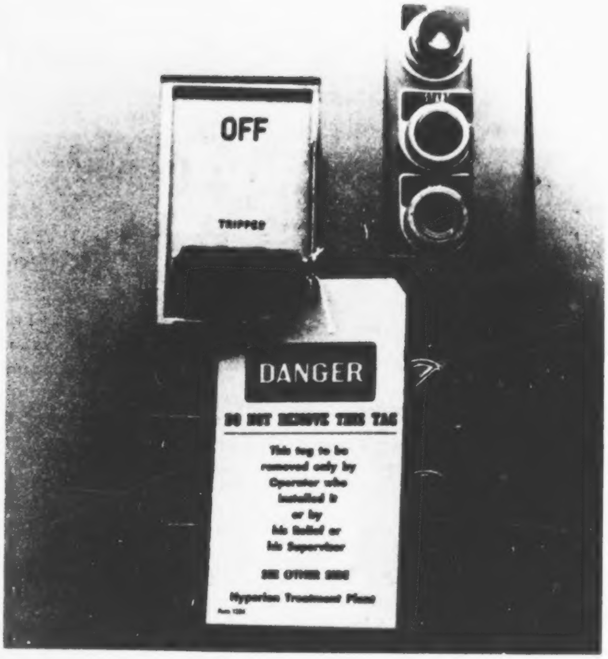

OFF
TRIPPED
DANGER
DO NOT REMOVE THIS TAG
This tag to be
removed only by
Operator who
installed it
or by
his Relief or
his Supervisor
SEE OTHER SIDE
Hyperion Treatment Plant

Fig. 8.33 "Tagged-out" controls

TABLE 8.2 MAINTENANCE AND TROUBLESHOOTING DUTIES

Instrument - Device	Maintenance - Service by the Operator
1. *THERMOMETERS*	
Liquid or Capillary	1. Check for leakage or breakage 2. Clean off surface 3. Replace with spare
Bimetallic	1. Clean sensing surface 2. Replace with spare
Thermocouples	1. Check for loose connections, corrosion, or damaged insulation, and repair as necessary
2. *PRESSURE GAGES*	
Manometer	1. Clean and/or add fluid 2. Check and tighten connections
Bourdon Tube, Diaphragm or Bellows	1. Check for sticking or damage 2. Replace with spare
3. *LEVEL INDICATORS*	
Float	1. Clean float 2. Check and clean cable and pulley; lubricate as necessary
Probes Electric Capacitance Ultrasonic	1. Check and clean connections 2. Clean probe if possible 3. Check power supply (fuse)
Bubbler Tube	1. Check air supply 2. Check air tube and clean
Diaphragm Box or Sight Tubes	1. Clean
4. *DENSITY METERS*	
Optical Ultrasonic Radioactive	1. Clean (flush) sensors with water 2. Check "zeroing" with water 3. Check power supply (fuse)
5. *RPM INDICATOR TACHOMETER*	
Cable Drive	1. Check cable, clean, lube, tighten
D.C. Generator	1. Check terminal connections 2. Check drive coupling
Strobe	1. Check battery or power supply 2. Check for burned out bulb
Pulse Detector	1. Check terminal connections 2. Check pulse sensor clearance
6. *VISUAL READ-OUTS*	
Circular or Strip Chart	1. Change charts 2. Check for irregular movements 3. Check power supply
Pens	1. Clean pen 2. Refill or replace ink cartridge
7. *METERS*	(Also see Chapter 15, Section 15.4, "Flow Measurements - Meters and Maintenance," Volume II, *OPERATION OF WASTEWATER TREATMENT PLANTS*)
Venturi	1. Check purge water 2. Check flow zero 3. Clean taps with bayonet, if appropriate
Orifice Plate	1. Check flow zero 2. Clean taps with bayonet, if appropriate
Magnetic	1. Check flow zero 2. Check power supply
Weirs	1. Clean weir face 2. Check level indicator
8. *ALARM FUNCTIONS - HIGH TEMPERATURE, PRESSURE & LEVEL*	
Lights	1. Test bulb, change as necessary
Audible Signal	1. Test for sound
9. *CONTROLLERS*	
Pneumatic	1. Check for air supply availability
Electronic	1. Check for power availability
Timers	1. Check to see that they are working
Auto Manual	1. Switch from one mode to the other, to see that they work
10. *INTEGRATORS*	
Mechanical or Electrical	1. Check power supply
11. *OTHER INSTRUMENTS*	
LEL Probe	1. Check zero setting 2. Check alarm function 3. Test with gas, if appropriate
DO Probe	1. Clean probe 2. Check for loose connections
pH Probe	1. Clean probe 2. Check electrolyte
Turbidimeter	1. Check meter zero
CH_4 or CO_2 Analyzer	1. Check for gas supply 2. Check for power supply
OTHER CONTROLS - INDICATORS	
On-Off Lights	1. Test bulbs
Percent Open-Closed	1. Manually check indicator against valve opening

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 488.

8.9A What kind of attention do instruments and controls require?

8.9B What information should you provide other operators before you start to work on an instrument or control?

8.10 ADDITIONAL READING

1. *PROCESS INSTRUMENTATION AND CONTROL SYSTEMS,* MOP OM-6. Publications Order Department, Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314. Order No. MOM6OHO. Price $24.00 to members; $32.00 to others.
2. *INSTRUMENTATION FOR WASTEWATER TREATMENT SYSTEMS,* by J.S. Samkoff, Technical Reprint IW-113, Graver Water, Division of the Graver Company, 2720, U.S. Highway 22, Union, New Jersey 07083.
3. *AUTOMATION AND INSTRUMENTATION,* M-2, AWWA Computer Services, American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 30002. Price $18.00 to members; $23.00 to others.
4. *WASTEWATER TREATMENT PLANT INSTRUMENTATION HANDBOOK.* Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order No. PB 86-108 636/AS. Cost $30.95.

8.11 ACKNOWLEDGMENT

Material in this chapter was reviewed by Norman Ole Thompson.

END OF LESSON 4 OF 4 LESSONS
ON
INSTRUMENTATION

Please answer the discussion and review questions before working the objective test.

DISCUSSION AND REVIEW QUESTIONS

(Lesson 4 of 4 Lessons)

Chapter 8. INSTRUMENTATION

Please write the answers to these questions in your notebook before continuing with the objective test. The problem numbering continues from Lesson 3.

16. Why are accurate air flow measurements very important in the activated sludge process?
17. How is the air compressor speed in RPM measured?
18. What precautions should be taken to ensure accurate dissolved oxygen readings in aeration tanks?
19. A low level alarm in a sludge digester could indicate what types of problems?
20. Why must the digester gas pressure be monitored in fixed cover digesters?
21. Where should combustible gas alarms be installed?
22. What special safety hazards may be encountered when maintaining and troubleshooting instruments and controls?

PLEASE WORK THE OBJECTIVE TEST NEXT.

SUGGESTED ANSWERS

Chapter 8. INSTRUMENTATION

Answers to questions on page 442.

8.0A Plants are being designed and constructed with sophisticated instrument and control systems because of tougher discharge and monitoring requirements and also to help operators do their job.

8.0B An instrument is a measuring device.

8.0C A control is a device or series of devices that effect some change due to some other change in conditions.

Answers to questions on page 446.

8.0D Instruments are used in place of or to assist the operator's sense of sight, smell, touch and hearing because of the need for:

1. Accuracy of the measurement,
2. Repeatability of the measurement,
3. Sensitivity of the measurement, and
4. Permanence of the measurement.

8.0E The sensitivity of a measurement is the ability to measure the smallest or largest value necessary.

8.0F An instrument's accuracy depends on the preciseness or exactness of the measurements. Repeatability is the ability of an instrument to measure something again and obtain the same answer that resulted previously.

Answers to questions on page 450.

8.1A Instruments are used instead of our human senses because they provide a more accurate, consistent, sensitive and permanent means of monitoring (measuring) treatment processes.

8.1B Instruments measure temperature, pressure, flow, level, density, velocity and analytical measurements (physical, chemical and biological).

8.1C Flow can be defined as a "flow rate" (volume passing a point at any given instant or time period) or as a "total flow or volume" (total volume passing a point within a specified time period).

Answers to questions on page 455.

8.2A Typical units of measurement for the listed parameters in both English and metric units.

Parameter	**English**	**Metric**
1. Temperature	°F or °R	°C or °K
2. Pressure	psi or psf in. H_2O or Hg	kg/sq cm or kg/sq m cm H_2O or Hg
3. Flow		
Liquids (volume)	cfs, GPM or MGD	*L*/s or cu m/s
Gases (volume)	cfm	cu m/s
Solids or Liquids (weight)	lb/hr	g/s
Solids (volume)	cu ft/day or cu yd/day	cu m/day
4. Level	in. or ft	cm or m
5. Density	lbs/cu ft	kg/cu m
6. Velocity		
Linear	ft/sec or ft/hr	m/sec or m/hr
Rotational	RPM	RPM

END OF ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 466.

8.3A Three different types of temperature measuring instruments or sensors are:

1. Liquid filled thermometer,
2. Bimetallic thermometer, and
3. Thermocouple.

8.3B The most common liquids used in manometers to measure pressures are water and mercury.

8.3C

Known	**Unknown**
Density of Water = 62.4 lbs/cu ft	Pressure, psi, if manometer reads: 1. 8 inches of water 2. 8 inches of mercury
Specific Gravity of Mercury = 13.55	

1. Determine pressure in psi if manometer reads 8 inches of water.

$$\begin{aligned}\text{Pressure, psi} &= \text{Density, lbs/cu in} \times \text{Height, in}\\ &= \frac{62.4 \text{ lbs/cu ft} \times 8 \text{ in}}{1728 \text{ cu in/cu ft}}\\ &= 0.29 \text{ psi}\end{aligned}$$

2. Determine pressure in psi if manometer reads 8 inches of mercury.

$$\begin{aligned}\text{Pressure, psi} &= \text{Density, lbs/cu in} \times \text{Height, in}\\ &= \frac{13.55 \times 62.4 \text{ lbs/cu ft} \times 8 \text{ in}}{1728 \text{ cu in/cu ft}}\\ &= 3.91 \text{ psi}\end{aligned}$$

Answers to questions on page 466.

8.4A The purpose of transmitting instruments is to send the variable, as measured by the measuring device (sensor), to another device for conversion to a usable number.

8.4B The different types of receivers include indicators, recorders, totalizers (integrators) and multipurpose.

Answers to questions on page 469.

8.5A The five common parts to a control system are:

1. Primary element or sensor,
2. Transmitter,
3. Measuring element or receiver,
4. Controlling element, and
5. Final element.

8.5B The common types of control methods include:

1. Open and closed loops,
2. Manual control,
3. On-off control,
4. Proportional control,
5. Proportional control with reset, and
6. Proportional control with reset derivative.

Answers to questions on page 471.

8.6A The purpose of recorders is keeping continuous and permanent records of process variables.

8.6B The two basic types of recorders found in treatment plants are circular charts and strip charts.

8.7A Integrators or totalizers are used in treatment plants to sum up the amount of liquid or gaseous flow.

END OF ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 475.

8.8A The preliminary treatment section could contain instrumentation monitoring and/or controlling the following functions:

1. Influent Level (high-low levels)
2. Influent Flow (rate)
3. Explosive Gas Detection (hydrocarbon, LEL)
4. Bar Screen Operation (On-Off)
5. Grit Removal (On-Off)
6. Ventilation System (On-Off)
7. Valves and Gates (Closed, percent Open)
8. Sump Pump (On-Off)
9. High Water Alarm

8.8B The influent level is an important indicator of the rate of inflow. The number of bar screens or grit channels on-line depends on the inflow rate. Abnormally low flows could indicate an obstruction in the influent sewer line or, worse yet, failure of the sewer pipe. A high water alarm could indicate a blockage at the bar screens or perhaps only a partially opened valve or gate hindering the flow downstream.

8.8C Gasoline or other petroleum products can be detected in a wet well by using an explosive or combustible gas detection instrument. This instrument may or may not be useful in detecting hydrocarbon concentrations which affect treatment, but it is necessary for safety reasons with regard to explosive gases and vapors.

8.8D Wet well ventilation systems must be kept operating continuously both for the operator's safety and for minimizing the accumulation of concentrations of moist or otherwise corrosive and toxic gases.

Answers to questions on page 477.

8.8E Instrumented activities that could concern an operator in primary treatment include:

1. Collector drive motor,
2. Flights,
3. Grease skimmers,
4. Sludge blanket depth,
5. Sludge pumps,
6. Sludge draw-off valve,
7. Sludge flow,
8. High water alarm, and
9. Water level control valve.

8.8F Flight movement can be detected by:

1. A pivoted stick moving every time a flight strikes it, or
2. An ultrasonic signal which is reflected by a passing flight.

8.8G Sludge pumps can be controlled or regulated by:

1. Turning the pumps on and off,
2. Using a timer control, and
3. Using a sludge density meter control.

8.8H Butterfly valves are used to control the flow to each primary tank to equalize the flow and promote the most efficient use of tanks in service.

END OF ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 480.

8.8I Air flow is usually measured by a differential pressure metering device such as an orifice plate.

8.8J Air pressure gages are usually placed at the air compressors and also downstream at main aeration lines.

8.8K Oil levels in air compressors may be measured manually by a dip stick, read from a sight glass or by the use of electronic or ultrasonic systems.

Answers to questions on page 483.

8.8L Activities that are usually instrumented or controlled in the anaerobic sludge digestion process include:

1. Raw sludge feed controller,
2. Digester tank level and alarms,
3. Digester sludge flow,
4. Digester gas flow,
5. Digester gas pressure,
6. Digester sludge temperature,
7. Digester heating system (steam, hot water),
8. Digester transfer and recirculation pumps,
9. Digester gas quality,
10. Combustible gas alarm, and
11. Digester gas mixing compressor.

8.8M Digested sludge flow would be recorded if the sludge receives additional treatment, such as dewatering or chemical conditioning.

8.8N Temperatures in an anaerobic sludge digester may be measured by:

1. A built-in temperature-sensing device such as a thermocouple,
2. Manually placing a thermometer in sludge running into the sample sink.

8.8O Digester transfer and recirculation pumps are used to mix the digester contents, transfer sludge between digesters, pump out digested sludge and pump supernatant or plant effluent in or out of digesters.

Answers to questions on page 486.

8.9A Instruments and controls need attention such as cleaning, adjusting, calibrating, repairing and/or replacement from time to time.

8.9B Before starting to work on an instrument or control, notify other operators what you are going to do, when you are going to do it, how long it will take, and what will be affected.

END OF ANSWERS TO QUESTIONS IN LESSON 4

OBJECTIVE TEST

Chapter 8. INSTRUMENTATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one answer to each question.

1. One of the most sophisticated and common control systems is the human body.
   1. True
   2. False

2. A control system is a measuring device.
   1. True
   2. False

3. Repeatability means measuring something over and over again until you get the same answer twice.
   1. True
   2. False

4. Gage pressure does not take into consideration the weight of the atmosphere above the earth.
   1. True
   2. False

5. A manometer with a vertical leg is more sensitive than a manometer with an inclining or sloping measuring leg.
   1. True
   2. False

6. In a control system, the final element is the device that controls the energy supplied to the process being controlled.
   1. True
   2. False

7. A recorder is a device that records information onto a sheet of paper that is moving at a specific speed.
   1. True
   2. False

8. In large treatment plants, all digesters are loaded at the same rate to evenly balance the digester loadings.
   1. True
   2. False

9. If you don't know how to maintain or troubleshoot instruments and controls, leave them alone and request assistance.
   1. True
   2. False

10. Special areas should be designated for instrument maintenance and storage and areas with high humidity and corrosive gases should be avoided.
    1. True
    2. False

11. Which of the following are measuring devices?
    1. Bathroom scale
    2. Computer
    3. Heater
    4. Ruler
    5. Thermometer

Questions 12, 13, and 14. In the human body the eyes are the (12) ________ the nervous system is (13) ________ and the brain is the (14) ________.

Answers to questions 12, 13, and 14.

1. Control logic
2. Indicator
3. Probe
4. Sensing instrument
5. Transmission system

15. The operation of a toilet bowl flush tank is an example of what type of control system?
    1. Biological and cybernetic
    2. Cybernetic and electrical
    3. Electrical and hydraulic
    4. Hydraulic and mechanical
    5. Mechanical and pneumatic

16. What method or device should you use to measure the diameter of a replacement pump shaft?
    1. Engineer's scale
    2. Metallic tape
    3. Micrometer
    4. Ruler
    5. Surveyor's chain

17. Temperature can be measured on which of the following scales?
    1. Celsius
    2. Fahrenheit
    3. Joule
    4. Kelvin
    5. Pascal

18. Common types of pressure gages include
    1. Bellows.
    2. Bourdon.
    3. Diaphragm.
    4. Parshall.
    5. Venturi.

19. Liquid levels may be measured by
    1. Bubbler tubes.
    2. Floats.
    3. Probes.
    4. Sight tubes.
    5. Ultrasonic sounds.

20. A tachometer measures
    1. Density.
    2. Distance.
    3. Rotational velocity.
    4. Temperature.
    5. Time.

21. The primary element in a control system is also called a
    1. Controller.
    2. Receiver.
    3. Recorder.
    4. Sensor.
    5. Transmitter.

22. The set point is the position at which the ____________ is set.
    1. Controller
    2. Receiver
    3. Recorder
    4. Sensor
    5. Transmitter

23. Different types of control systems include
    1. Manual.
    2. On-Off.
    3. Project.
    4. Proportional.
    5. Ratio.

24. Abnormally low flows into a treatment plant could indicate
    1. A broken sewer pipe.
    2. A downstream blockage.
    3. A failure in the sewer system.
    4. An industrial waste discharge.
    5. An obstruction in the sewer.

25. What types of alarm systems are usually installed on grit channel equipment?
    1. Collection drive system on or off
    2. Explosive gas detection
    3. High water level
    4. Motors tripped-out on overload
    5. Oxygen deficiency

26. Sludge blanket depths may be measured by use of
    1. Bubbler tubes.
    2. Floats connected to cables and pulleys.
    3. A hose and an aspirator.
    4. Pressure gages.
    5. Ultrasonic transmitters and receivers.

27. Primary sludge flow is usually metered by
    1. A magnetic flow meter.
    2. An orifice.
    3. A Parshall flume.
    4. A Venturi meter.
    5. A weir.

28. Excessive air compressor lubrication oil temperatures may indicate
    1. Heater malfunction.
    2. High oil levels.
    3. Inoperative oil coolers.
    4. Low oil levels.
    5. Motor overload.

29. Which of the following factors are usually measured by air compressor vibration sensing devices?
    1. Acceleration
    2. Displacement
    3. Flow
    4. Time
    5. Velocity

30. A high level alarm in a sludge digester could indicate
    1. A control system malfunction.
    2. A digested sludge valve left open.
    3. An inoperative digested sludge withdrawal system.
    4. A plugging of the overflow.
    5. A possible leak or break somewhere in the system.

31. Digester gas flows are commonly measured by the use of
    1. Orifice plates.
    2. Positive displacement meters.
    3. Rotameters.
    4. Turbine meters.
    5. Venturi meters.

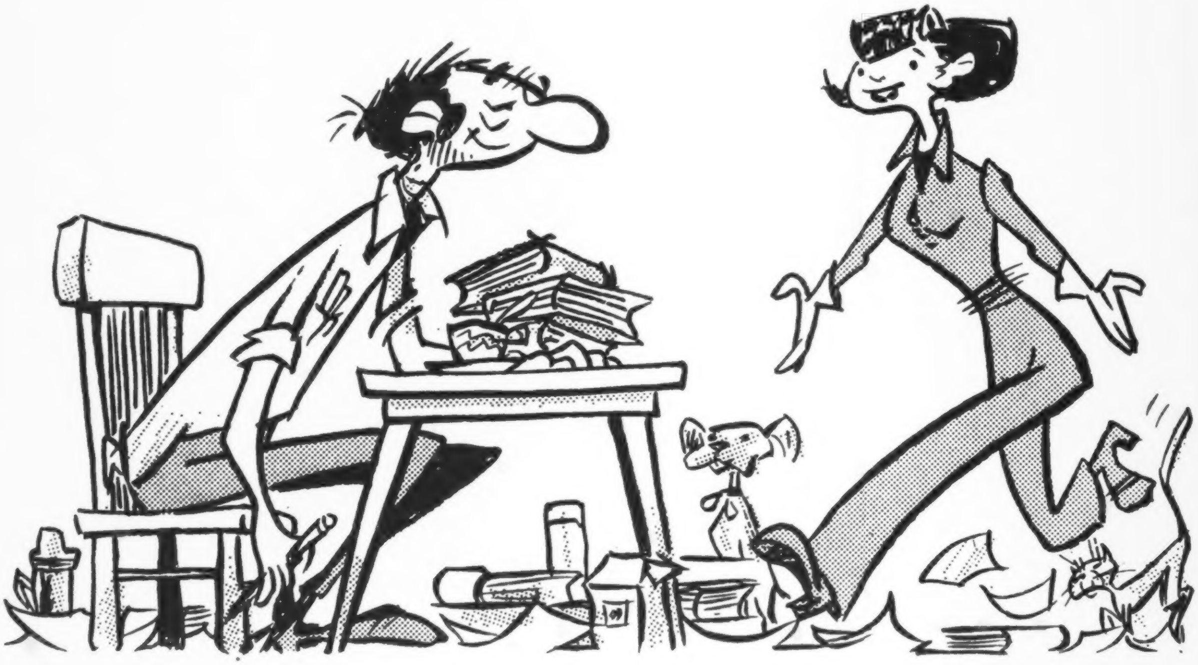
32. Which of the following maintenance services can be performed by operators on Venturi meters?
    1. Check flow zero
    2. Check level indicator
    3. Check power supply
    4. Check purge water
    5. Clean taps

33. Which of the following maintenance services can be performed by operators on LEL meters?
    1. Check alarm function
    2. Check electrolyte
    3. Check zero setting
    4. Check probe
    5. Test with gas

● END OF OBJECTIVE TEST ●

CONGRATULATIONS

You've worked hard and completed a very difficult program.



APPENDIX

FINAL EXAMINATION
AND
SUGGESTED ANSWERS

GLOSSARY

SUBJECT INDEX

FINAL EXAMINATION

VOLUME III

This final examination was prepared *TO HELP YOU* review the material in this manual. The questions are divided into four types:

1. True-false,
2. Multiple choice,
3. Problems, and
4. Short answer.

To work this examination:

1. Write the answer to each question in your notebook,
2. After you have worked a group of questions (you decide how many), check your answers with the suggested answers at the end of this exam, and
3. If you missed a question and don't understand why, reread the material in the manual.

You may wish to use this examination for review purposes when preparing for civil service and certification examinations.

Since you have already completed this course, you do not have to send your answers to California State University, Sacramento.

True-False

1. Microorganisms breakdown nitrate compounds before sulfate compounds to obtain oxygen.
    1. True
    2. False
2. Hydrogen sulfide gas is a more serious problem at lower temperatures than at higher temperatures.
    1. True
    2. False
3. Chemicals are the only method available for operators to control odors.
    1. True
    2. False
4. The grey appearance of out-of-service activated carbon that has been in service for along time indicates that the activated carbon is worn out.
    1. True
    2. False
5. Pure oxygen systems may be used to supply oxygen to any of the activated sludge process modes — conventional, step-feed, complete mix or contact stabilization.
    1. True
    2. False
6. Cold liquid oxygen (LOX) can cause skin burns.
    1. True
    2. False
7. Changes in activated sludge quality cause changes in the settling characteristics of the sludge.
    1. True
    2. False
8. The activated sludge process is controlled by attempting to achieve preconceived levels of individual variables such as MLSS, MCRT and F/M ratio.
    1. True
    2. False
9. Primary sludges have specific gravities closer to that of water than secondary sludges.
    1. True
    2. False
10. If gasification problems develop in a gravity thickener as a result of excessive sludge retention times, the rate of sludge withdrawal should be increased so as to lower the sludge blanket depth with a subsequent lowering of the sludge retention time.
    1. True
    2. False
11. Sludge should be thickened as much as possible in order to minimize digestion time in aerobic digesters.
    1. True
    2. False
12. Chemical stabilization of sludges finds application at overloaded plants and at plants experiencing stabilization facility upsets.
    1. True
    2. False
13. In the wet oxidation process, an increase in oxidation is due primarily to reacting the sludge with greater quantities of oxygen at elevated temperatures and pressures.
    1. True
    2. False
14. Primary sludges dewater more readily and require more chemical conditioners than secondary sludges.
    1. True
    2. False

15. The ideal operating belt speed for a belt filter press is the fastest the operator can maintain without "washing out" the belt.
    1. True
    2. False

16. A burnout occurs in a multiple hearth furnace when the sludge feed has been stopped and the fire burns out.
    1. True
    2. False

17. Storage often must be provided in sludge treatment and disposal systems to accommodate differences between sludge disposal rates and sludge production rates.
    1. True
    2. False

18. Addition of alum will increase the alkalinity in the water being treated during the coagulation process.
    1. True
    2. False

19. The formation of limestone (calcium carbonate) is not a serious problem in lime systems used for phosphorus removal.
    1. True
    2. False

20. In the luxury uptake phosphorus removal process, bacteria release phosphorus in an aerobic release tank.
    1. True
    2. False

21. The method of irrigation depends on the type of crop being grown.
    1. True
    2. False

22. An instrument is a device that causes changes to occur.
    1. True
    2. False

23. The scales on an indicator may be straight, curved, or circular in shape.
    1. True
    2. False

24. The headworks ventilation system must be kept operating both for the operator's safety and for minimizing the accumulation of concentrations of moist or otherwise corrosive and toxic gases.
    1. True
    2. False

25. Short-circuiting is not caused by differences in water density due to different temperatures existing at the surface and the bottom of the clarifier.
    1. True
    2. False

Multiple Choice

1. Inorganic gases found around treatment plants include
    1. Ammonia.
    2. Hydrogen sulfide.
    3. Mercaptans.
    4. Methane.
    5. Skatole.

2. Cryogenic oxygen plants are usually shut down ____________ for maintenance.
    1. Once every six months
    2. Once every year
    3. Once every two years
    4. Once every five years
    5. Once every ten years

3. Return activated sludge (RAS) flow rate may be adjusted or controlled by which of the following techniques?
    1. Food/Microorganisms Ratio
    2. Mean Cell Residence Time (MCRT)
    3. Monitoring the depth of the sludge blanket
    4. SVI approach
    5. Settleability approach

4. Which of the following items could indicate that a high organic waste load has reached an activated sludge process?
    1. Decrease in DO residual in aeration tank
    2. Decrease in nutrients in effluent from secondary clarifier
    3. Decrease in turbidity in effluent from secondary clarifier
    4. Increase in DO residual in aeration tank
    5. Increase in turbidity in effluent from secondary clarifier

5. Major factors affecting biological nutrification include
    1. Dissolved oxygen.
    2. Nitrogenous food.
    3. pH.
    4. Toxic materials.
    5. Wastewater temperature.

6. Which of the following items are possible causes of sludge rising and solids carry-over in a gravity thickener with a clear liquid fuel?
    1. Blanket disturbances
    2. Chemical inefficiencies
    3. Excessive loadings
    4. Gasification
    5. Septic feed

7. In dissolved air flotation thickeners, floated solids are kept out of the effluent by use of
    1. Effluent baffles.
    2. Hardware cloth screens.
    3. Macroscreens.
    4. Scum scrapers.
    5. Water sprays.

8. A belt filter press is processing secondary sludges. Some of the sludge is squeezing out from between the belts and contaminating the effluent by falling into the filtrate trays. How could this problem be corrected?
    1. Blend primary sludge with the secondary sludge
    2. Build baffles around the belts
    3. Chlorinate the effluent
    4. Filter the effluent
    5. Move the filtrate trays

9. If no coagulation occurs in a chemical treatment process, which of the following items should be inspected?
   1. Actual feeder output by catching a timed sample
   2. Applied water for a significant change
   3. Feed chemical strength
   4. Skimmer arms
   5. Tank drain valve

10. Abnormal operating conditions for microscreens include
    1. High flows.
    2. High pH levels.
    3. Low applied water flows.
    4. Low pH flows.
    5. Toxic wastes.

11. Which of the following items should be inspected or checked before starting a chemical feeder?
    1. Direction and rotation of moving parts in motors
    2. Operation of control lights on control panel
    3. Operation of safety lock-out switches
    4. Proper voltage
    5. Size of overload protection

12. Which of the following items would you check if laboratory tests indicated high turbidity and suspended solids in the effluent of a gravity filter?
    1. Check for excessive head loss
    2. Determine filter aid dosages
    3. Examine backwash cycle for complete wash
    4. Inspect for damaged bed due to backwashing
    5. Look for fluctuating flows that could cause breakthrough

13. Phosphorus removal efficiencies by the lime precipitation process are affected by
    1. Changes in pH.
    2. Performance of lime feed equipment.
    3. Plugged pumps or piping.
    4. Recarbonation system.
    5. Small straggler floc.

14. The hydraulic loading for a phosphate stripper depends on the
    1. Ability of the aerobic phosphate stripper to remain aerobic.
    2. Ability of the anaerobic phosphate stripper to remain anaerobic.
    3. BOD loading of the unit.
    4. Dissolved oxygen of the activated sludge.
    5. pH of the wastewater being treated.

15. Which of the following chemical properties are used in the classification of irrigation waters?
    1. BOD
    2. Boron
    3. Chloride
    4. pH
    5. Total dissolved solids

16. Which of the following tests are performed on the soils in an effluent disposal on land program?
    1. BOD
    2. Cation exchange capacity
    3. Conductivity
    4. DO
    5. pH

17. Which method or device should you use to measure the diameter of a replacement pump shaft?
    1. Engineer's scale
    2. Metallic tape
    3. Micrometer
    4. Ruler
    5. Surveyor's chain

18. The primary element in a control system is also called a
    1. Controller.
    2. Receiver.
    3. Recorder.
    4. Sensor.
    5. Transmitter.

19. Sludge blanket depths may be measured by the use of
    1. Bubbler tubes.
    2. Floats connected to cables and pulleys.
    3. A hose and an aspirator.
    4. Pressure gages.
    5. Ultrasonic transmitters and receivers.

20. Which of the following factors are usually measured by air compressor vibration sensing devices?
    1. Acceleration
    2. Displacement
    3. Flow
    4. Time
    5. Velocity

Short Answer

1. Define the following terms:
   a. Absorption
   b. Oxidation
   c. Stripped odors

2. Define the following items:
   a. Batch process
   b. Bulking
   c. Coagulation
   d. Filamentous bacteria
   e. RAS

3. Why are pure oxygen reactors in the activated sludge process staged?

4. How can variations or fluctuations in influent organic loadings be smoothed out before the aeration basin?

5. Define the following items:
   a. Elutriation
   b. Vector

6. List three process alternatives for each of the following types of sludge processing alternatives:
   1. Thickening,
   2. Conditioning, and
   3. Volume reduction.

7. List the factors that affect the performance of dissolved air flotation (DAF) thickeners.

8. How can an operator control the digestion time in an aerobic digester?

9. What is the purpose of wetting dry polymers?

10. How can the cake dryness from a vacuum filter be increased?

11. What safety precautions are required for handling ferric chloride in concentrated solutions?

12. Why should the backwash water for a gravity filter be of the best quality available?

13. Why are chemicals commonly used with a filtration process?

14. Define the following terms:
    a. Recalcine
    b. Slake

15. What is luxury uptake of phosphorus?

16. Define the following terms:
    a. Reclamation
    b. Recycle

17. List possible causes of clogging in a recharge well and possible cures for each cause.

18. Define the following terms:
    a. Offset
    b. Set point

19. Why are treatment plants being designed and constructed with sophisticated instrument-control systems?

20. Why are instruments used instead of our human senses of seeing, hearing, touching, and smelling?

21. What does a thermocouple measure?

22. What does a Bourdon Tube measure?

23. What is the purpose of transmitting instruments?

24. Why are detection devices for explosive gases installed in the headworks of treatment plants?

25. How is air flow measured in the activated sludge process?

Problems

1. Determine the desired waste activated sludge (WAS) flow rate using the F/M control technique. The influent flow is 4.0 MGD, total aeration tank volume is 0.8 MG, COD to aeration tank is 110 mg/L, the mixed liquor suspended solids (MLSS) are 3100 mg/L and 69 percent volatile matter, the RAS suspended solids are 6,400 mg/L and the desired food to microorganism (F/M) ratio is 0.28 lbs COD/day/lb MLVSS. Current WAS flow rate is 0.35 MGD.

2. Estimate the total volume (sum of primary and secondary) of sludge produced in gallons per day from a 2 MGD activated sludge plant. Primary clarifier influent suspended solids are 300 mg/L and 120 mg/L in the effluent. Primary effluent BOD is 175 mg/L and secondary effluent BOD is 25 mg/L. The bacterial growth rate, Y, is 0.50 lbs SS per lb BOD. Primary sludge solids are 5 percent solids and secondary solids are 1.5 percent solids.

3. Jar tests indicate that a waste activated sludge flow of 35,000 GPD with a solids concentration of 1.4 percent sludge solids will require 20 pounds per day of Polymer A or 180 pounds per day of Polymer B for successful gravity thickening. Polymer A is a dry product and costs $2.20 per dry pound. Polymer B is a liquid product and costs $0.22 per liquid pound. Find the cost of using both Polymer A and B in dollars per ton of sludge.

4. Polymer is supplied at a concentration of 0.5 pounds polymer per gallon of water being treated. The polymer feed pump delivers a flow of 0.18 GPM and the flow to the pressure filters is 6,000 GPM. Calculate the concentration or dose (mg/*L*) of polymer in the water applied to the filter.

5. Determine the suspended solids and BOD loadings on a dissolved air flotation unit if the flow is 0.8 MGD and the influent suspended solids are 1,800 mg/L with a BOD of 150 mg/L. What is the percent removal of suspended solids if the effluent suspended solids are 100 mg/L?

SUGGESTED ANSWERS FOR FINAL EXAMINATION

VOLUME III

True-False

1. True Microorganisms breakdown nitrate compounds before sulfate compounds to obtain oxygen.
2. False Hydrogen sulfide gas is a more serious problem at higher temperatures than at lower temperatures.
3. False Good housekeeping and biological odor reduction towers are methods used to control odors in addition to chemicals.
4. False The grey appearance of out-of-service activated carbon is caused by salts. The activated carbon may not be worn out.
5. True Pure oxygen systems may be used to supply oxygen to any of the activated sludge process modes — conventional, step-feed, complete mix or contact stabilization.
6. True Cold liquid oxygen can cause skin burns.
7. True Changes in activated sludge quality cause changes in the settling characteristics of the sludge.
8. False The activated sludge process is *NOT* controlled by attempting to achieve preconceived levels of individual variables such as MLSS, MCRT and F/M ratio.
9. False Secondary sludges have specific gravities *CLOSER* to that of water than primary sludges.
10. True If gasification problems develop in a gravity thickener as a result of excessive sludge retention times, the rate of sludge withdrawal should be increased so as to lower the sludge blanket depth with a subsequent lowering of the sludge retention time.
11. False Sludge should be thickened as much as possible in order to *MAXIMIZE* digestion time in aerobic digesters.
12. True Chemical stabilization of sludge finds application at overloaded plants and at plants experiencing stabilization facility upsets.
13. True In the wet oxidation process, an increase in oxidation is due primarily to reacting the sludge with greater quantities of oxygen at elevated temperatures and pressures.
14. False Primary sludges dewater more readily and require *LESS* chemical conditioners than secondary sludges.
15. False The ideal operating belt speed for a belt filter press is the *SLOWEST* the operator can maintain without "washing out" the belt.
16. False A burnout occurs in a multiple hearth furnace when the sludge feed has been stopped and the fire continues to burn.
17. True Storage often must be provided in sludge treatment and disposal systems to accommodate differences between sludge disposal rates and sludge production rates.
18. False Alum *REDUCES* the alkalinity in the water being treated during the coagulation process.
19. False Formation of limestone (calcium carbonate) is a serious problem in lime systems used for phosphorus removal.
20. False In the luxury uptake phosphorus removal process, bacteria release phosphorus in an *ANAEROBIC* release tank.
21. True The method of irrigation depends on the type of crop being grown.
22. False An instrument is a measuring device.
23. True The scales on an indicator may be straight, curved, or circular in shape.
24. True The headworks ventilation system must be kept operating both for the operator's safety and for minimizing the accumulation of concentrations of moist or otherwise corrosive and toxic gases.
25 False Short-circuiting may be caused by differences in water density due to different temperatures existing at the surface and the bottom of the clarifier.

Multiple Choice

1. 1, 2, 4 Ammonia, hydrogen sulfide and methane are inorganic gases found around treatment plants.
2. 2 Cryogenic oxygen plants are usually shut down once every year for maintenance.
3. 3, 4, 5 RAS flow rate may be adjusted by
    1. Monitoring the depth of the sludge blanket,
    2. SVI approach, and
    3. Settleability approach.
4. 1, 2, 5 When a high organic waste load reaches an activated sludge process, the DO residual will drop due to organism activity, effluent nutrients will drop due to a lack of nutrients in most industrial wastes, and effluent turbidity will increase due to a reduction in the level of treatment.

5. 1, 2, 3, 4, 5 All items listed are major factors affecting biological nitrification — DO, nitrogenous food, pH, toxic materials, and wastewater temperature.

6. 1, 2, 3, 4, 5 Blanket disturbances, chemical inefficiencies, excessive loadings, gasification and septic feed are all possible causes of sludge rising and solids carry-over in a gravity thickener with a clear liquid level.

7. 1 Effluent baffles are used to keep floated solids out of the effluent of dissolved air flotation thickeners.

8. 1 Blend primary sludge with secondary sludge to stop secondary sludges from squeezing out from between belts and contaminating the effluent by falling into the filtrate trays.

9. 1, 2, 3 If no coagulation occurs in a chemical treatment process, inspect applied water for a significant change, actual feeder output by catching a timed sample, and feed chemical strength. Also inspect the chemical feed pump operation, chemical supply and valve positions and solution carrier water flow and valve positions.

10. 1, 2, 3, 4 Abnormal operating conditions for microscreens include high flows, high pH levels, low applied water flows and low pH levels.

11. 1, 2, 3, 4, 5 Before starting a chemical feeder, inspect or check for direction of rotation of moving parts in motors, operation of control lights on control panel, operation of safety lock-out switches, proper voltage, and size of overload protection.

12. 1, 2, 3, 4, 5 If laboratory tests indicate high turbidity and suspended solids in the effluent of a gravity filter, check for excessive head loss, determine filter aid dosages, examine backwash cycle for complete wash, inspect for damaged bed due to backwashing, and look for fluctuating flows that could cause breakthrough.

13. 1, 2, 3, 4, 5 Phosphorus removal efficiencies by the lime precipitation process are affected by changes in pH, performance of the lime feed equipment, plugged pumps or piping, recarbonation system and small straggler floc.

14. 2, 4 The hydraulic loading for a phosphate stripper depends on the ability of the anaerobic phosphate stripper to remain anaerobic and the dissolved oxygen of the activated sludge.

15. 2, 3, 5 Chemical properties used in the classification of irrigation waters include boron, chloride and total dissolved solids.

16. 2, 3, 5 Tests performed on the soils in an effluent disposal on land program include cation exchange capacity, conductivity and pH.

17. 3 A micrometer should be used to measure the diameter of a replacement pump shaft.

18. 4 The primary element in a control system is also called a sensor.

19. 3, 5 Sludge blanket depths may be measured by use of a hose and an aspirator or ultrasonic transmitters and receivers.

20. 1, 2, 5 Air compressor vibration sensing devices usually measure acceleration, displacement and velocity.

Short Answer

1. Define the following terms:
   a. Absorption. Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).
   b. Oxidation. Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatement, organic matter is oxidized to more stable substances.
   c. Stripped odors. Odors that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed and/or tumbled over media.

2. Define the following terms.
   a. Batch process. A treatment process in which a tank or reactor is filled, the water is treated, and the tank is emptied. The tank may then be filled and the process repeated.
   b. Bulking. Clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge becomes too light and will not settle properly.
   c. Coagulation. The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, and draining or filtering.
   d. Filamentous bacteria. Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomycetes.
   e. RAS. **R**eturn **A**ctivated **S**ludge, mg/*L*. Settled activated sludge that is collected in the secondary clarifier and returned to the aeration basin to mix with incoming raw or primary settled wastewater.

3. Pure oxygen reactors are staged to increase the efficiency of the use of oxygen.

4. Organic loadings can be smoothed out by the use of an equalizing tank and also by keeping the contents of the equalizing tank well mixed.

5. Define the following terms:
   a. Elutriation. The washing of digested sludge in plant effluent. The objective is to remove (wash out) fine particulates and/or the alkalinity in the sludge. This process reduces the demand for conditioning chemicals and improves settling or filtering characteristics of the solids.
   b. Vector. An insect or other organism capable of transmitting germs or other agents of disease.

6. Types of Sludge Processing Alternatives

Thickening	Conditioning	Volume Reduction
1. Gravity	1. Chemical	1. Drying
2. Flotation	2. Thermal	2. Incineration
3. Centrifugation	3. Elutriation	3. Composting
	4. Wet Oxidation	

7. The performance of DAF thickeners depends on (1) type and age of the feed sludge, (2) solids and hydraulic loading, (3) air to solids (A/S) ratio, (4) recycle rate, and (5) sludge blanket depth.

8. The operator can control digestion time by controlling the degree of sludge thickening prior to digestion. The thicker the sludge, the longer the digestion time.

9. The purpose of wetting dry polymers is to produce a properly mixed solution that will not have balls of undissolved polymer.

10. Cake dryness from a vacuum filter can be increased by (1) increasing vacuum, (2) reducing drum speed, and (3) improving chemical conditioning.

11. Safety precautions required for handling ferric chloride in concentrated forms should be the same as those for acids. Wear protective clothing, face shields and gloves. Flush off all splashes on clothing and skin immediately.

12. If nonfiltered water is supplied to the backwash system, clogging of the underdrain system may occur.

13. Chemicals are commonly used with a filtration process as coagulants for the solids and turbidity to aid in their removal by filtration.

14. Define the following terms:
    a. Recalcine. A lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).
    b. Slake. To become mixed with water so that a true chemical reaction takes place, such as in the slaking of lime.

15. Luxury uptake of phosphorus is a biological process whereby the bacteria normally found in the activated sludge treatment portion of the secondary wastewater treatment plant are withdrawn to an environment without oxygen (anaerobic) for release of phosphorus. When the bacteria are returned to an ideal environment, the first thing they take in is phosphorus. This phosphorus take-up is known as luxury uptake.

16. Define the following terms:
    a. Reclamation. The operation or process of changing the condition or characteristics of water so that improved uses can be achieved.
    b. Recycle. The use of water or wastewater within (internally) a facility before it is discharged to a treatment system.

17.

Possible Causes of Clogging	Possible Cures for Cause
1. Slimes	1. Chlorination or allow well to rest.
2. Carbon fines	2. Remove fines by passing the water through a sand/anthracite filter.

18. Define the following terms:
    a. Offset. The difference between the actual value and the desired value (or set point) characteristic of proportional controllers that do not incorporate reset action.
    b. Set point. The position at which the control or controller is set. This is the same as the desired value of the process variable.

19. Plants are being designed and constructed with sophisticated instrument and control systems because of tougher discharge and monitoring requirements and also to help operators do their job.

20. Instruments are used instead of our human senses because they provide a more accurate, consistent, sensitive and permanent means of monitoring (measuring) treatment processes.

21. A thermocouple measures temperature.

22. A Bourdon Tube measures pressure.

23. The purpose of transmitting instruments is to send the variable, as measured by the measuring device (sensor), to another device for conversion to a usable number.

24. Detection devices for explosive gases are installed in the headworks of treatment plants for safety reasons if explosive gases or vapors may reach and accumulate in the headworks.

25. Air flow in the activated sludge process is usually measured by a differential pressure metering device such as an orifice plate.

Problems

1. **Known** — **Unknown**

Infl. Flow, MGD = 4.0 MGD — WAS Flow,MGD

Tank Vol., MG = 0.8 MG

COD, mg/L = 110 mg/L

MLSS, mg/L = 3,100 mg/L

MLSS VM, % = 69%

RAS SS, mg/L = 6,400 mg/L

Desired F/M $\frac{\text{lbs COD/day}}{\text{lb MLVSS}} = 0.28 \frac{\text{lbs COD/day}}{\text{lb MLVSS}}$

Current WAS, MGD = 0.35 MGD

a. Determine COD applied in pounds per day.

$$\begin{aligned}\text{COD, lbs/day} &= \text{Flow, MGD} \times \text{COD, mg/L} \times 8.34\ \text{lbs/gal}\\ &= 4\ \text{MGD} \times 110\ \text{mg/L} \times 8.34\ \text{lbs/gal}\\ &= 3{,}670\ \text{lbs/day}\end{aligned}$$

b. Determine the desired pounds of MLVSS.

$$\begin{aligned}\text{Desired MLVSS, lbs} &= \frac{\text{COD applied, lbs/day}}{\text{F/M, lbs COD/day/lb MLVSS}}\\ &= \frac{\text{3,760 lbs COD/day}}{\text{0.28 lbs COD/day/lb MLVSS}}\\ &= \text{13,107 lbs}\\ &\ \text{Use 13,100 lbs}^{*}\end{aligned}$$

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* From a practical standpoint, you can't measure MLSS or MLVSS any closer than to the nearest 100 pounds.

c. Determine the desired pounds MLSS.

$$\begin{aligned}\text{Desired MLSS, lbs} &= \frac{\text{Desired MLVSS, lbs}}{\text{MLSS VM portion}}\\ &= \frac{\text{13,107 lbs}}{0.69}\\ &= \text{18,996 lbs}\\ &\ \text{Use 19,000 lbs}\end{aligned}$$

d. Determine actual MLSS pounds under aeration.

$$\begin{aligned}\text{Actual MLSS, lbs} &= \text{Tank Vol, MG} \times \text{MLSS, mg/L} \times \text{8.34 lbs/gal}\\ &= \text{0.8 MG} \times \text{3,100 mg/L} \times \text{8.34 lbs/gal}\\ &= \text{20,683 lbs}\\ &\ \text{Use 20,700 lbs}\end{aligned}$$

e. Calculate the additional WAS, MGD, to maintain the desired food to microorganism (F/M) ratio.

$$\begin{aligned}\text{Additional WAS Flow, MGD} &= \frac{\text{Actual MLSS, lbs} - \text{Desired MLSS, lbs}}{\text{RAS SS, mg/L} \times \text{8.34 lbs/gal}}\\ &= \frac{\text{20,700 lbs} - \text{19,000 lbs}}{\text{6,400 mg/L} \times \text{8.34 lbs/gal}}\\ &= \text{0.032 MGD} \times \text{694 GPM/MGD}\\ &= \text{22 GPM}\end{aligned}$$

f. Calculate the total WAS flow in MGD and GPM.

$$\begin{aligned}\text{Total WAS Flow, MGD} &= \text{Current WAS Flow, MGD} + \text{Additional WAS Flow, MGD}\\ &= \text{0.35 MGD} + \text{0.032 MGD}\\ &= \text{0.35 MGD} \times \text{694 GPM/MGD}\\ &= \text{243 GPM}\end{aligned}$$

2. **Known**

Flow, MGD = 2 MGD
Prim Effl SS, mg/L = 120 mg/L
Prim Infl SS, mg/L = 300 mg/L
Prim Effl BOD, mg/L = 175 mg/L
Sec Effl BOD, mg/L = 25 mg/L
Y, lbs SS/lb BOD = 0.5 lbs SS/lb BOD
Prim Sludge Solids, % = 5%
Sec Sludge Solids, % = 1.5%

Unknown

Volume of Sludge, gal/day

a. Calculate the amount of dry primary sludge produced in pounds per day.

$$\begin{aligned}\text{Primary Sludge, lbs/day} &= \text{Flow, MGD (In SS, mg/L} - \text{Ef SS, mg/L) 8.34 lbs/gal}\\ &= \text{2 MGD (300 mg/L} = \text{120 mg/L) 8.34 lbs/gal}\\ &= \text{3000 lbs/day (dry solids)}\end{aligned}$$

b. Calculate the amount of BOD removed by the secondary system in lbs BOD per day.

$$\begin{aligned}\text{BOD Removed, lbs/day} &= \text{Flow, MGD (BOD In, mg/L} - \text{BOD Out, mg/L) 8.34 lbs/gal}\\ &= \text{2 MGD (175 mg/L} - \text{25 mg/L) 8.34 lbs/gal}\\ &= \text{2500 lbs BOD/day}\end{aligned}$$

c. Determine the secondary sludge produced in terms of dry sludge solids per day.

$$\begin{aligned}\text{Sludge Produced lbs dry solids/day} &= \text{BOD Removed, lbs BOD/day} \times \text{Y, } \frac{\text{lbs Sl Sol Prod/day}}{\text{lbs BOD Removed/day}}\\ &= \text{2500 lbs BOD/day} \times \frac{\text{0.5 lbs Sl Sol/day}}{\text{1 lb BOD/day}}\\ &= \text{1250 lbs dry sludge solids/day}\end{aligned}$$

d. Estimate the total volume of sludge produced in gallons per day.

$$\begin{aligned}\text{Sludge Volume, gal/day} &= \text{Primary Sludge Volume, gal/day} + \text{Secondary Sludge Volume, gal/day}\\ &= \frac{\text{Prim Sludge, lbs dry solids/day}}{\text{Prim Sludge Solids, \%/100\%} \times \text{8.34 lbs/gal}}\\ &\quad + \frac{\text{Sec Sludge, lbs/dry solids/day}}{\text{Sec Sludge Solids, \%/100\%} \times \text{8.34 lbs/gal}}\\ &= \frac{\text{3000 lbs/day}}{\text{5\%/100\%} \times \text{8.34 lbs/gal}} + \frac{\text{1250 lbs/day}}{\text{1.5\%/100\%} \times \text{8.34 lbs/gal}}\\ &= \text{7200 gal/day} + \text{10,000 gal/day}\\ &= \text{17,200 gal/day}\end{aligned}$$

3. **Known**

Jar Tests on Waste Activated Sludge
Flow, GPD = 35,000 GPD
Sl Sol, % = 1.4%
Polymer A, lbs/day = 20 lbs/day
Polymer B, lbs/day = 180 lbs/day
Polymer A, $/lb = $2.20/dry lb
Polymer B, $/lb = $0.22/liquid lb

Unknown

Costs of Polymers A and B, $/ton of sludge

a. Determine the polymer dosage in pounds of polymer per ton of sludge for both Polymer A and B.

1. Calculate the tons of dry sludge solids per day treated by the polymers.

$$\begin{aligned}\text{Sludge, tons/day} &= \frac{\text{Flow, GPD} \times \text{8.34 lbs/gal} \times \text{Sl Sol, \%/100\%}}{\text{2000 lbs/ton}}\\ &= \frac{\text{35,000 gal/day} \times \text{8.34 lbs/gal} \times \text{1.5\%/100\%}}{\text{2000 lbs/ton}}\\ &= \text{2.19 tons/day}\end{aligned}$$

2. Calculate the dosage of Polymer A in dry pounds of polymer per ton of sludge solids.

$$\begin{aligned}\text{Polymer A Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} &= \frac{\text{Amount of Polymer A, lbs/day}}{\text{Sludge, tons/day}}\\ &= \frac{\text{20 lbs Polymer A/day}}{\text{2.19 tons/day}}\\ &= \text{9.1 lbs dry Polymer A/ton sludge}\end{aligned}$$

3. Calculate the dosage for Polymer B in liquid pounds of polymer per ton of sludge solids.

$$\begin{aligned}\text{Polymer B Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} &= \frac{\text{Amount of Polymer B, lbs/day}}{\text{Sludge, tons/day}}\\ &= \frac{180 \text{ lbs Polymer B/day}}{2.19 \text{ tons/day}}\\ &= 82.2 \text{ lbs liquid Polymer B/ton sludge}\end{aligned}$$

b. Calculate cost for Polymer A in dollars of polymer per ton of sludge solids treated.

$$\begin{aligned}\text{Cost, \$/ton} &= \text{Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{Polymer Cost, \$/lb}\\ &= 9.1 \ \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{\$2.20/lb polymer}\\ &= \text{\$20.02/ton of sludge}\end{aligned}$$

c. Calculate the cost for Polymer B in dollars of polymer per ton of sludge solids treated.

$$\begin{aligned}\text{Cost, \$/ton} &= \text{Dose, } \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{Polymer Cost, \$/lb}\\ &= 82.2 \ \frac{\text{lbs polymer}}{\text{ton sludge}} \times \text{\$0.22/lb polymer}\\ &= \text{\$18.08/ton of sludge}\end{aligned}$$

4.

Known		Unknown
Polymer Conc., lb/gal	= 0.5 lbs/gal	Polymer Dose, mg/L
Polymer Pump, GPM	= 0.18 GPM	
Flow to Filter, GPM	= 6,000 GPM	

Calculate the polymer dose in mg/L.

$$\begin{aligned}\text{Dose, mg/}L &= \frac{\text{Flow, gal/min} \times \text{Conc., lbs polymer/gal}}{\text{Flow, gal/min} \times 8.34 \text{ lbs/gal}}\\ &= \frac{0.18 \text{ gal/min} \times 0.5 \text{ lbs/gal}}{6{,}000 \text{ gal/min} \times 8.34 \text{ lbs/gal}}\\ &= \frac{0.09 \text{ lbs polymer}}{50{,}040 \text{ lbs water}} \times \frac{1{,}000{,}000}{1 \text{ M}}\\ &= 1.8 \text{ mg/}L\end{aligned}$$

5.

Known		Unknown
Flow, MGD	= 0.8 MGD	1. SS Loading, lbs/day
Infl SS, mg/L	= 1,800 mg/L	2. BOD Loading, lbs/day
Effl SS, mg/L	= 100 mg/L	3. SS Removal, %
Infl BOD, mg/L	= 150 mg/L	

a. Calculate the influent suspended solids loading in pounds per day.

$$\begin{aligned}\text{SS Loading, lbs/day} &= \text{Flow, MGD} \times \text{Infl SS, mg/}L \times 8.34 \text{ lbs/gal}\\ &= 0.8 \text{ MGD} \times 1800 \text{ mg/}L \times 8.34 \text{ lbs/gal}\\ &= 12{,}000 \text{ lbs suspended solids/day}\end{aligned}$$

b. Calculate the influent BOD loading in pounds BOD per day.

$$\begin{aligned}\text{BOD Loading, lbs/day} &= \text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34 \text{ lbs/gal}\\ &= 0.8 \text{ MGD} = \times\ 150 \text{ mg/}L \times 8.34 \text{ lbs/gal}\\ &= 1{,}000 \text{ lbs BOD/day}\end{aligned}$$

c. Determine the percent suspended solids removal.

$$\begin{aligned}\text{SS Removal, \%} &= \frac{(\text{Infl SS, mg/}L - \text{Effl SS, mg/}L)}{\text{Infl SS, mg/}L}\\ &= \frac{(1800 \text{ mg/}L - 100 \text{ mg/}L)}{1800 \text{ mg/}L}\, 100\%\\ &= 94.4\%\end{aligned}$$

GLOSSARY

A Summary of the Words Defined

in

ADVANCED WASTE TREATMENT

Project Pronunciation Key

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This key is designed solely to aid operators in this program.

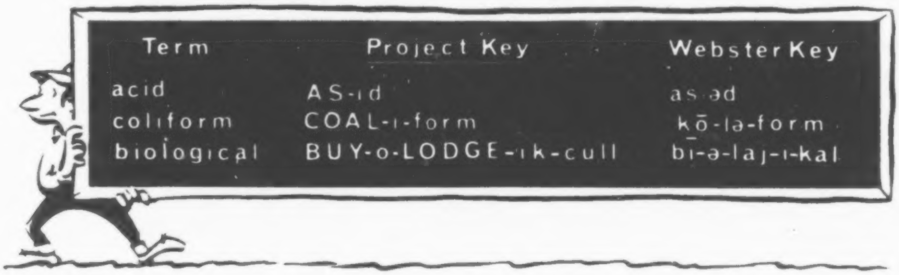
You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation key. Each key will be different from each other and from this key. Examples of the difference between the key used in this program and the Webster's *NEW WORLD DICTIONARY* "Key"[1] are shown below:

In using this key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	SYLLABLE				
WORD	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word, *ACID*, has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the key useful in unlocking the pronunciation of any new word.



Term	Project Key	Webster Key
acid	AS-id	as·əd
coliform	COAL-i-form	kō-lə-form
biological	BUY-o-LODGE-ik-cull	bī-ə-laj-i-kal

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[1] *The Webster's* NEW WORLD DICTIONARY, *College Edition, 1968, was chosen rather than an unabridged dictionary because of its availability to the operator.*

GLOSSARY

ABS ABS

Alkyl **B**enzene **S**ulfonate. A type of surfactant, or surface active agent, present in synthetic detergents in the United States before 1965. ABS was especially troublesome because it caused foaming and resisted breakdown by biological treatment processes. ABS has been replaced in detergents by **l**inear **a**lkyl **s**ulfonate (LAS) which is biodegradable.

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACID ACID

(1) A substance that tends to lose a proton. (2) A substance that dissolves in water with the formation of hydrogen ions. (3) A substance containing hydrogen which may be replaced by metals to form salts.

ACIDITY ACIDITY

The capacity of water or wastewater to neutralize bases. Acidity is expressed in milligrams per liter of equivalent calcium carbonate. Acidity is not the same as pH because water does not have to be strongly acidic (low pH) to have a high acidity. Acidity is a measure of how much base can be added to a liquid without causing a great change in pH.

ACTIVATED SLUDGE (ACK-ta-VATE-ed sluj) ACTIVATED SLUDGE

Sludge particles produced in raw or settled wastewater (primary effluent) by the growth of organisms (including zoogleal bacteria) in aeration tanks in the presence of dissolved oxygen. The term "activated" comes from the fact that the particles are teeming with bacteria, fungi, and protozoa. Activated sludge is different from primary sludge in that the sludge particles contain many living organisms which can feed on the incoming wastewater.

ACTIVATED SLUDGE PROCESS (ACK-ta-VATE-ed sluj) ACTIVATED SLUDGE PROCESS

A biological wastewater treatment process which speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to wastewater and the mixture (mixed liquor) is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank) as needed. The remaining wastewater then undergoes more treatment.

ADSORPTION (add-SORP-shun) ADSORPTION

The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another substance.

ADVANCED WASTE TREATMENT ADVANCED WASTE TREATMENT

Any process of water renovation that upgrades treated wastewater to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes. Typical processes include chemical treatment and pressure filtration. Also called TERTIARY TREATMENT.

AERATION (air-A-shun) AERATION

The process of adding air. In wastewater treatment, air is added to freshen wastewater and to keep solids in suspension. With mixtures of wastewater and activated sludge, adding air provides mixing and oxygen for the microorganisms treating the wastewater.

AERATION LIQUOR (air-A-shun) AERATION LIQUOR

Mixed liquor. The contents of the aeration tank including living organisms and material carried into the tank by either untreated wastewater or primary effluent.

AERATION TANK (air-A-shun) AERATION TANK

The tank where raw or settled wastewater is mixed with return sludge and aerated. The same as aeration bay, aerator, or reactor.

AEROBES AEROBES

Bacteria that must have molecular (dissolved) oxygen (DO) to survive.

AEROBIC (AIR-O-bick) AEROBIC

A condition in which "free" or dissolved oxygen is present in the aquatic environment.

AEROBIC BACTERIA (AIR-O-bick back-TEAR-e-ah) AEROBIC BACTERIA

Bacteria which will live and reproduce only in an environment containing oxygen which is available for their respiration (breathing), namely atmospheric oxygen or oxygen dissolved in water. Oxygen combined chemically, such as in water molecules (H_2O), cannot be used for respiration by aerobic bacteria.

AEROBIC DECOMPOSITION (AIR-O-bick) AEROBIC DECOMPOSITION

The decay or breaking down of organic material in the presence of "free" or dissolved oxygen.

AEROBIC DIGESTION (AIR-O-bick) AEROBIC DIGESTION

The breakdown of wastes by microorganisms in the presence of dissolved oxygen. Waste sludge is placed in a large aerated tank where aerobic microorganisms decompose the organic matter in the sludge. This is an extension of the activated sludge process.

AEROBIC PROCESS (AIR-O-bick) AEROBIC PROCESS

A waste treatment process conducted under aerobic (in the presence of "free" or dissolved oxygen) conditions.

AGE TANK AGE TANK

A tank used to store a known concentration of chemical solution for feed to a chemical feeder. Also called a "day tank."

AGGLOMERATION (a-GLOM-er-A-shun) AGGLOMERATION

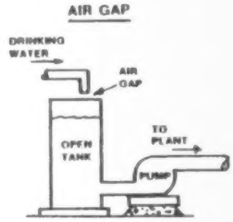
The growing or coming together of small scattered particles into larger flocs or particles which settle rapidly. Also see FLOC.

AIR BINDING AIR BINDING

The clogging of a filter, pipe or pump due to the presence of air released from water.

AIR GAP AIR GAP

An open vertical drop, or vertical empty space, between a drinking (potable) water supply and the point of use in a wastewater treatment plant. This gap prevents back siphonage because there is no way wastewater can reach the drinking water.



AIR LIFT AIR LIFT

A special type of pump. This device consists of a vertical riser pipe submerged in the wastewater or sludge to be pumped. Compressed air is injected into a tail piece at the bottom of the pipe. Fine air bubbles mix with the wastewater or sludge to form a mixture lighter than the surrounding water which causes the mixture to rise in the discharge pipe to the outlet. An air-lift pump works similar to the center stand in a percolator coffee pot.

AIR PADDING AIR PADDING

Pumping dry air into a container to assist with the withdrawal of a liquid or to force a liquid gas such as chlorine or sulfur dioxide out of a container.

ALGAE (AL-gee) ALGAE

Microscopic plants which contain chlorophyll and float or are suspended and live in water. They also may be attached to structures, rocks, or other similar substances.

ALIQUOT (AL-li-kwot) ALIQUOT

Portion of a sample.

ALKALI ALKALI

Any of certain soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical processes such as water or wastewater treatment.

ALKALINITY (AL-ka-LIN-ity) ALKALINITY

The capacity of water or wastewater to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surroundings.

AMPEROMETRIC (am-PURR-o-MET-rick) AMPEROMETRIC

A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is a means of measuring concentrations of certain substances in water.

ANAEROBES ANAEROBES

Bacteria that do not need molecular (dissolved) oxygen (DO) to survive.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" or dissolved oxygen is *NOT* present in the aquatic environment.

ANAEROBIC BACTERIA (AN-air-O-bick back-TEAR-e-ah) ANAEROBIC BACTERIA

Bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen. Anaerobic bacteria obtain their oxygen supply by breaking down chemical compounds which contain oxygen, such as sulfate (SO_4).

ANAEROBIC DECOMPOSITION (AN-air-O-bick) ANAEROBIC DECOMPOSITION

The decay or breaking down of organic material in an environment containing no "free" or dissolved oxygen.

ANAEROBIC DIGESTION (AN-air-O-bick) ANAEROBIC DIGESTION

Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance: (1) *SAPROPHYTIC* bacteria break down complex solids to volatile acids, and (2) *METHANE FERMENTERS* break down the acids to methane, carbon dioxide, and water.

ANHYDROUS (an-HI-drous) ANHYDROUS

Very dry. No water or dampness is present.

ANION ANION

A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of electric potential.

ASEPTIC (a-SEP-tick) ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

ASPIRATE (ASS-per-RATE) ASPIRATE

Use of a hydraulic device (aspirator or eductor) to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a sump pump.

BOD (BEE-OH-DEE) BOD

Biochemical Oxygen Demand. The rate at which microorganisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BTU (BEE-TEA-YOU) BTU

British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

BACTERIA (back-TEAR-e-ah) BACTERIA

Bacteria are living organisms, microscopic in size, which consist of a single cell. Most bacteria utilize organic matter for their food and produce waste products as the result of their life processes.

BACTERIAL CULTURE (back-TEAR-e-al) BACTERIAL CULTURE

In the case of activated sludge, the bacterial culture refers to the group of bacteria classed as *AEROBES*, and facultative organisms, which covers a wide range of organisms. Most treatment processes in the United States grow facultative organisms which utilize the carbonaceous (carbon compounds) BOD. Facultative organisms can live when oxygen resources are low. When "nitrification" is required, the nitrifying organisms are *OBLIGATE AEROBES* (require oxygen) and must have at least 0.5 mg/*L* of dissolved oxygen throughout the whole system to function properly.

BAFFLE BAFFLE

A flat board or plate, deflector, guide or similar device constructed or placed in flowing water, wastewater, or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids.

BASE BASE

A compound which dissociates (separates) in aqueous solution to yield hydroxyl ions.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated, and the tank is emptied. The tank may then be filled and the process repeated.

BENCH SCALE ANALYSIS BENCH SCALE ANALYSIS

A method of studying different ways of treating wastewater and solids on a small scale in a laboratory.

BENZENE BENZENE

An aromatic hydrocarbon (C_6H_6) which is a colorless, volatile, flammable liquid. Benzene is obtained chiefly from coal tar and is used as a solvent for resins and fats in the manufacture of dyes.

BIOASSAY (BUY-o-ass-SAY) BIOASSAY

(1) A way of showing or measuring the effect of biological treatment on a particular substance or waste, or (2) a method of determining toxic effects of industrial wastes or other wastes by using live organisms such as fish for test organisms.

BIOCHEMICAL OXYGEN DEMAND (BOD) BIOCHEMICAL OXYGEN DEMAND (BOD)

The rate at which microorganisms use the oxygen in water or wastewater while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BIOCHEMICAL OXYGEN DEMAND (BOD) TEST BIOCHEMICAL OXYGEN DEMAND (BOD) TEST

A procedure that measures the rate of oxygen use under controlled conditions of time and temperature. Standard test conditions include dark incubation at 20°C for a specified time (usually five days).

BIODEGRADABLE (BUY-o-dee-GRADE-able) BIODEGRADABLE

Organic matter that can be broken down by bacteria to more stable forms which will not create a nuisance or give off foul odors.

BIODEGRADATION (BUY-o-de-grah-DAY-shun) BIODEGRADATION

The breakdown of organic matter by bacteria to more stable forms which will not create a nuisance or give off foul odors.

BIOFLOCCULATION (BUY-o-flock-u-LAY-shun) BIOFLOCCULATION

The clumping together of fine, dispersed organic particles by the action of certain bacteria and algae. This results in faster and more complete settling of the organic solids in wastewater.

BIOMASS (BUY-o-MASS) BIOMASS

A mass or clump of living organisms feeding on the wastes in wastewater, dead organisms and other debris. This mass may be formed for, or function as, the protection against predators and storage of food supplies. Also see ZOOGLEAL MASS.

BLANK BLANK

A bottle containing only dilution water or distilled water, but the sample being tested is not added. Tests are frequently run on a *SAMPLE* and a *BLANK* and the differences compared.

BLINDING BLINDING

The clogging of the filtering medium of a microscreen or a vacuum filter when the holes or spaces in the media become sealed off due to a buildup of grease or the material being filtered.

BOUND WATER BOUND WATER

Water contained within the cell mass of sludges or strongly held on the surface of colloidal particles.

BREAKOUT OF CHLORINE BREAKOUT OF CHLORINE

A point at which chlorine leaves solution as a gas because the chlorine feed rate is too high. The solution is saturated and cannot dissolve any more chlorine.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water or wastewater until the chlorine demand has been satisfied and further additions of chlorine result in a residual that is directly proportional to the amount added beyond the breakpoint.

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

BUFFER ACTION BUFFER ACTION

The action of certain ions in solution in opposing a change in hydrogen-ion concentration.

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in pH.

BUFFER SOLUTION BUFFER SOLUTION

A solution containing two or more substances which, in combination, resist any marked change in pH following addition of moderate amounts of either strong acid or base.

BULKING (BULK-ing) BULKING

Clouds of billowing sludge that occur throughout secondary clarifiers and sludge thickeners when the sludge becomes too light and will not settle properly.

CALORIE (KAL-o-ree) CALORIE

The amount of heat required to raise the temperature of one gram of water one degree Celsius.

CARBONACEOUS STAGE (car-bun-NAY-shus) CARBONACEOUS

A stage of decomposition that occurs in biological treatment processes when aerobic bacteria, using dissolved oxygen, change carbon compounds to carbon dioxide. Sometimes referred to as "first-stage BOD" because the microorganisms attack organic or carbon compounds first and nitrogen compounds later. Also see NITRIFICATION STAGE.

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of steel and iron surfaces in contact with water, wastewater or soil.

CATION EXCHANGE CAPACITY CATION EXCHANGE CAPACITY

The ability of a soil or other solid to exchange cations (positive ions such as calcium, Ca^{+2}) with a liquid.

CAVITATION (CAV-i-TAY-shun) CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller. The collapse of this gas pocket or bubble drives water into the impeller with a terrific force that can cause pitting on the impeller surface.

CENTRATE CENTRATE

The water leaving a centrifuge after most of the solids have been removed.

CENTRIFUGE CENTRIFUGE

A mechanical device that uses centrifugal or rotational forces to separate solids from liquids.

CHEMICAL EQUIVALENT CHEMICAL EQUIVALENT

The weight in grams of a substance that combines with or displaces one gram of hydrogen. Chemical equivalents usually are found by dividing the formula weight by its valence.

CHEMICAL OXYGEN DEMAND or COD CHEMICAL OXYGEN DEMAND or COD

A measure of the oxygen-consuming capacity of inorganic and organic matter present in wastewater. COD is expressed as the amount of oxygen consumed from a chemical oxidant in mg/*L* during a specific test. Results are not necessarily related to the biochemical oxygen demand because the chemical oxidant may react with substances that bacteria do not stabilize.

CHEMICAL PRECIPITATION CHEMICAL PRECIPITATION

(1) Precipitation induced by addition of chemicals. (2) The process of softening water by the addition of lime or lime and soda ash as the precipitants.

CHLORAMINES (KLOR-a-means) CHLORAMINES

Chloramines are compounds formed by the reaction of chlorine with ammonia.

CHLORINATION (KLOR-i-NAY-shun) CHLORINATION

The application of chlorine to water or wastewater, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.

CHLORINE DEMAND CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to wastewater and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

Chlorine Demand, mg/*L* = Chlorine Applied, mg/*L* − Chlorine Residual, mg/*L*

CHLORINE REQUIREMENT CHLORINE REQUIREMENT

The amount of chlorine which is needed for a particular purpose. Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or destroying some chemical in the water. In each case a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLORORGANIC (chloro-or-GAN-nick) CHLORORGANIC

Chlororganic compounds are organic compounds combined with chlorine. These compounds generally originate from, or are associated with, living or dead organic materials.

CILIATES (SILLY-ates) CILIATES

A class of protozoans distinguished by short hairs on all or part of their bodies.

CLARIFICATION (KLAIR-i-fi-KAY-shun) CLARIFICATION

Any process or combination of processes the main purpose of which is to reduce the concentration of suspended matter in a liquid.

CLARIFIER (KLAIR-i-fire) CLARIFIER

Settling Tank, Sedimentation Basin. A tank or basin in which wastewater is held for a period of time, during which the heavier solids settle to the bottom and the lighter material will float to the water surface.

COAGULANT AID COAGULANT AID

Any chemical or substance used to assist or modify coagulation.

COAGULANTS (co-AGG-you-lents) COAGULANTS

Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining or filtering.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The use of chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the liquids by settling, skimming, draining or filtering.

COLIFORM (COAL-i-form) COLIFORM

One type of bacteria. The presence of coliform-group bacteria is an indication of possible pathogenic bacterial contamination. The human intestinal tract is one of the main habitats of coliform bacteria. They may also be found in the intestinal tracts of warm-blooded animals, and in plants, soil, air, and the aquatic environment. Fecal coliforms are those coliforms found in the feces of various warm-blooded animals; whereas the term "coliform" also includes other environmental sources.

COLLOIDS (KOL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown concentrations of water quality indicators in a sample by measuring the sample's color intensity. The color of the sample after the addition of specific chemicals (reagents) is compared with colors of known concentrations.

COMBINED AVAILABLE CHLORINE COMBINED AVAILABLE CHLORINE

The concentration of chlorine which is combined with ammonia (NH_3) as chloramine or as other chloro derivatives, yet is still available to oxidize organic matter.

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

That portion of the total residual chlorine which remains in water or wastewater at the end of a specified contact period and reacts chemically and biologically as chloramines or organic chloramines.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water or wastewater to produce a combined chlorine residual. The residual may consist of chlorine compounds formed by the reaction of chlorine with natural or added ammonia (NH_3) or with certain organic nitrogen compounds.

COMBINED SEWER COMBINED SEWER

A sewer designed to carry both sanitary wastewaters and storm- or surface-water runoff.

COMMINUTION (com-mi-NEW-shun) COMMINUTION

Shredding. A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment. *COMMINUTION* and *SHREDDING* usually mean the same thing.

COMMINUTOR (com-mi-NEW-ter) COMMINUTOR

A device used to reduce the size of the solid chunks in wastewater by shredding (comminuting). The shredding action is like many scissors cutting or chopping to shreds all the large influent solids material.

COMPOSITE (PROPORTIONAL) SAMPLE (com-POZ-it) COMPOSITE (PROPORTIONAL) SAMPLE

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOUND COMPOUND

A pure substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride - Na Cl) is a compound.

CONING (CONE-ing) CONING

Development of a cone-shaped flow of liquid, like a whirlpool, through sludge. This can occur in a sludge hopper during sludge withdrawal when the sludge becomes too thick. Part of the sludge remains in place while liquid rather than sludge flows out of the hopper. Also called "coring."

CONTACT STABILIZATION CONTACT STABILIZATION

Contact stabilization is a modification of the conventional activated sludge process. In contact stabilization, two aeration tanks are used. One tank is for separate re-aeration of the return sludge for at least four hours before it is permitted to flow into the other aeration tank to be mixed with the primary effluent requiring treatment.

CONTINUOUS PROCESS CONTINUOUS PROCESS

A treatment process in which water is treated continuously in a tank or reactor. The water being treated continuously flows into the tank at one end, is treated as it flows through the tank, and flows out the opposite end as treated water.

CONVENTIONAL TREATMENT CONVENTIONAL TREATMENT

The pretreatment, sedimentation, flotation, trickling filter, activated sludge and chlorination wastewater treatment processes.

CROSS CONNECTION CROSS CONNECTION

A connection between drinking (potable) water and an unsafe water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

CRYOGENIC (cry-o-JEN-nick) CRYOGENIC

Low temperature.

DO (DEE-OH) DO

Abbreviation of Dissolved Oxygen. DO is the atmospheric oxygen dissolved in water or wastewater.

DATEOMETER (day-TOM-uh-ter) DATEOMETER

A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

DAY TANK DAY TANK

A tank used to store a known concentration of chemical solution for feed to a chemical feeder. Also called an "age tank."

DECHLORINATION (dee-KLOR-i-NAY-shun) DECHLORINATION

The removal of chlorine from the effluent of a treatment plant.

DECIBEL DECIBEL

A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average pain level.

DECOMPOSITION, DECAY DECOMPOSITION, DECAY

Processes that convert unstable materials into more stable forms by chemical or biological action. Waste treatment encourages decay in a controlled situation so that material may be disposed of in a stable form. When organic matter decays under anaerobic conditions (putrefaction), undesirable odors are produced. The aerobic processes in common use for wastewater treatment produce much less objectional odors.

DEFINING DEFINING

A process that arranges the activated carbon particles according to size. This process is also used to remove small particles from granular contactors to prevent excessive head loss.

DEGRADATION (de-grah-DAY-shun) DEGRADATION

The conversion of a substance to simpler compounds. For example, the degradation of organic matter to carbon dioxide and water.

DENITRIFICATION DENITRIFICATION

A condition that occurs when nitrite or nitrate ions are reduced to nitrogen gas and bubbles are formed as a result of this process. The bubbles attach to the biological flocs and float the flocs to the surface of the secondary clarifiers. This condition is often the cause of rising sludge observed in secondary clarifiers or gravity thickeners.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DESICCATOR (DESS-i-KAY-tor) DESICCATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DETENTION TIME DETENTION TIME

The time required to fill a tank at a given flow or the theoretical time required for a given flow of wastewater to pass through a tank.

DETRITUS (dee-TRI-tus) DETRITUS

The heavy, coarse mixture of grit and organic material carried by wastewater.

DEW POINT DEW POINT

The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air.

DEWATER DEWATER

To remove or separate a portion of the water present in a sludge or slurry.

DEWATERABLE DEWATERABLE

This is a property of a sludge related to the ability to separate the liquid portion from the solid, with or without chemical conditioning. A material is considered dewaterable if water will readily drain from it.

DIAPHRAGM PUMP DIAPHRAGM PUMP

The pump in which a flexible diaphragm, generally of rubber or equally flexible material, is the operating part. It is fastened at the edges in a vertical cylinder. When the diaphragm is raised suction is exerted, and when it is depressed, the liquid is forced through a discharge valve.

DIATOM DIATOM

A group of microscopic, unicellular, marine or fresh-water algae having siliceous (consisting of silica) cell walls.

DIATOMACEOUS EARTH DIATOMACEOUS EARTH

A fine, siliceous earth consisting mainly of the skeletal remains of diatoms.

DIFFUSED-AIR AERATION DIFFUSED-AIR AERATION

A diffused air activated sludge plant takes air, compresses it, and then discharges the air below the water surface of the aerator through some type of air diffusion device.

DIFFUSER DIFFUSER

A device (porous plate, tube, bag) used to break the air stream from the blower system into fine bubbles in an aeration tank or reactor.

DIGESTER (die-JEST-er) DIGESTER

A tank in which sludge is placed to allow decomposition by microorganisms. Digestion may occur under anaerobic (more common) or aerobic conditions.

DISCHARGE HEAD DISCHARGE HEAD

The pressure (in feet (meters) or pounds per square inch (kilograms per square centimeter)) on the discharge side of a pump. The pressure can be measured from the center line of the pump to the hydraulic grade line of the water in the discharge pipe.

DISINFECTION (dis-in-FECT-shun) DISINFECTION

The process designed to kill most microorganisms in wastewater, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water and wastewater treatment plants. Compare with STERILIZATION.

DISSOLVED OXYGEN DISSOLVED OXYGEN

Molecular oxygen dissolved in water or wastewater, usually abbreviated DO.

DISTILLATE (DIS-tuh-late) DISTILLATE

In the distillation of a sample, a portion is evaporated; the part that is condensed afterwards is the distillate.

DISTRIBUTOR DISTRIBUTOR

The rotating mechanism that distributes the wastewater evenly over the surface of a trickling filter or other process unit. Also see FIXED SPRAY NOZZLE.

DOCTOR BLADE DOCTOR BLADE

A blade used to remove any excess solids that may cling to the outside of a rotating screen.

DRAIN TILE SYSTEMS DRAIN TILE SYSTEMS

A system of tile pipes buried under the crops that collect percolated waters and keep the groundwater table below the ground surface to prevent ponding.

DRAINAGE WELLS DRAINAGE WELLS

Wells that can be pumped to lower the groundwater table and prevent ponding.

DROOP DROOP

The difference between the actual value and the desired value (or set point) characteristics of proportional controllers that do not incorporate reset action. Also called OFFSET.

DYNAMIC HEAD DYNAMIC HEAD

When a pump is operating, the vertical distance (in feet or meters) from a point to the energy grade lines. Also see TOTAL DYNAMIC HEAD and STATIC HEAD.

EDUCTOR (e-DUCK-tor) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump; sometimes used instead of a suction pump.

EFFLORESCENCE (EF-low-RESS-ense) EFFLORESCENCE

The powder or crust formed on a substance when moisture is given off upon exposure to the atmosphere.

EFFLUENT (EF-lu-ent) EFFLUENT

Wastewater or other liquid — raw, partially or completely treated — flowing *FROM* a basin, treatment process, or treatment plant.

ELECTRO-CHEMICAL CORROSION ELECTRO-CHEMICAL CORROSION

The decomposition of a material by: (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, and (3) galvanic corrosion caused by differential electrolysis.

ELECTRO-CHEMICAL PROCESS ELECTRO-CHEMICAL PROCESS

A process that causes the deposition or formation of a seal or coating of a chemical element or compound by the use of electricity.

ELECTRO-MAGNETIC FORCES ELECTRO-MAGNETIC FORCES

Forces resulting from electrical charges that either attract or repel particles. Particles with opposite charges are attracted to each other. For example, a particle with positive charges is attracted to a particle with negative charges. Particles with similar charges repel each other. A particle with positive charges is repelled by a particle with positive charges and a particle with negative charges is repelled by another particle with negative charges.

ELECTROLYSIS (ELECT-TROLLEY-sis) ELECTROLYSIS

The decomposition of material by an electric current.

ELECTROLYTE (ELECT-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC PROCESS (ELECT-tro-LIT-ick) ELECTROLYTIC PROCESS

A process that causes the decomposition of a chemical compound by the use of electricity.

ELECTRON ELECTRON

An extremely small (microscopic), negatively charged particle. An electron is much too small to be seen with a microscope.

ELEMENT ELEMENT

A substance which cannot be separated into substances of other kinds by ordinary chemical means. For example, sodium (Na) is an element.

ELUTRIATION (e-LOO-tree-A-shun) ELUTRIATION

The washing of digested sludge in plant effluent. The objective is to remove (wash out) fine particulates and/or alkalinity in sludge. This process reduces the demand for conditioning chemicals and improves settling or filtering characteristics of the solids.

EMULSION (e-MULL-shun) EMULSION

A liquid mixture of two or more liquid substances not normally dissolved in one another, but one liquid held in suspension in the other.

END POINT END POINT

Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs which is called the *END POINT* of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter. The completion of a desired chemical reaction.

ENDOGENOUS (en-DODGE-en-us) ENDOGENOUS

A reduced level of respiration (breathing) in which organisms break down compounds within their own cells to produce the oxygen they need.

ENERGY GRADE LINE (EGL) ENERGY GRADE LINE (EGL)

A line that represents the elevation of energy head (in feet) of water flowing in a pipe, conduit or channel. The line is drawn above the hydraulic grade line a distance equal to the velocity head of the water flowing at each section or point along the pipe or channel.

ENTERIC ENTERIC

Intestinal.

ENZYMES (EN-zimes) ENZYMES

Enzymes are organic substances which are produced by living organisms and speed up chemical changes.

EQUALIZING BASIN EQUALIZING BASIN

A holding basin in which variations in flow and composition of liquid are averaged. Such basins are used to provide a flow of reasonably uniform volume and composition to a treatment unit. Also called a balancing reservoir.

ESTUARIES (ES-chew-wear-eez) ESTUARIES

Bodies of water which are located at the lower end of a river and are subject to tidal fluctuations.

EVAPOTRANSPIRATION (e-VAP-o-trans-spi-RAY-shun) EVAPOTRANSPIRATION

The total water removed from an area by transpiration (plants) and by evaporation from soil, snow and water surfaces.

EXPLOSIMETER EXPLOSIMETER

An instrument used to detect explosive atmospheres. When the Lower Explosive Limit (L.E.L.) of an atmosphere is exceeded, an alarm signal on the instrument is activated.

F/M RATIO F/M RATIO

Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

$$\begin{aligned}\frac{\text{Food}}{\text{Microorganisms}} &= \frac{\text{BOD, lbs/day}}{\text{MLVSS, lbs}}\\ &= \frac{\text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34\text{ lbs/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/}L \times 8.34\text{ lbs/gal}}\\ \text{or} \quad &= \frac{\text{BOD, kg/day}}{\text{MLVSS, kg}}\end{aligned}$$

FACULTATIVE (FACK-ul-TAY-tive) FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FACULTATIVE POND (FACK-ul-TAY-tive) FACULTATIVE POND

The most common type of pond in current use. The upper portion (supernatant) is aerobic, while the bottom layer is anaerobic. Algae supply most of the oxygen to the supernatant.

FILAMENTOUS BACTERIA (FILL-a-MEN-tuss) FILAMENTOUS BACTERIA

Organisms that grow in a thread or filamentous form. Common types are thiothrix and actinomycetes.

FILTER AID FILTER AID

A chemical (usually a polymer) added to water to help remove fine colloidal suspended solids.

FIXED FIXED

A sample is "fixed" in the field by adding chemicals that prevent the water quality indicators of interest in the sample from changing before final measurements are performed later in the lab.

FIXED SPRAY NOZZLE FIXED SPRAY NOZZLE

Cone-shaped spray nozzle used to distribute wastewater over the filter media, similar to a lawn sprinkling system. A deflector or steel ball is mounted within the cone to spread the flow of wastewater through the cone, thus causing a spraying action. Also see DISTRIBUTOR.

FLAME POLISHED FLAME POLISHED

Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

FLIGHTS FLIGHTS

Scraper boards, made from redwood or other rot-resistant woods or plastic, used to collect and move settled sludge or floating scum.

FLOC FLOC

Groups or clumps of bacteria and particles or coagulants and impurities that have come together and formed a cluster. Found in aeration tanks, secondary clarifiers and chemical precipitation processes.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles to form larger particles.

FLOW-EQUALIZATION SYSTEM FLOW-EQUALIZATION SYSTEM

A device or tank designed to hold back or store a portion of peak flows for release during low-flow periods.

FOOD/MICROORGANISM RATIO FOOD/MICROORGANISM RATIO

Food to microorganism ratio. A measure of food provided to bacteria in an aeration tank.

$$\begin{aligned}\frac{\text{Food}}{\text{Microorganisms}} &= \frac{\text{BOD, lbs/day}}{\text{MLVSS, lbs}}\\ &= \frac{\text{Flow, MGD} \times \text{BOD, mg/}L \times 8.34\text{ lbs/gal}}{\text{Volume, MG} \times \text{MLVSS, mg/}L \times 8.34\text{ lbs/gal}}\\ \text{or} \quad &= \frac{\text{BOD, kg/day}}{\text{MLVSS, kg}}\end{aligned}$$

Commonly abbreviated F/M Ratio.

FORCE MAIN FORCE MAIN

A pipe that conveys wastewater under pressure from the discharge side of a pump to a point of gravity flow.

FREE AVAILABLE CHLORINE FREE AVAILABLE CHLORINE

The amount of chlorine available in water. This chlorine may be in the form of dissolved gas (Cl_2), hypochlorous acid (HOCl) or hypochlorite ion (OCl^-), but does not include chlorine combined with an amine (ammonia or nitrogen) or other organic compound.

FREE AVAILABLE RESIDUAL CHLORINE FREE AVAILABLE RESIDUAL CHLORINE

That portion of the total residual chlorine remaining in water or wastewater at the end of a specified contact period. Residual chlorine will react chemically and biologically as hypochlorous acid (HOCl) or hypochlorite ion (OCl^-).

FREE CHLORINE FREE CHLORINE

Free chlorine is chlorine (Cl_2) in a liquid or gaseous form. Free chlorine combines with water to form hypochlorous (HOCl) and hydrochloric (HCl) acids. In wastewater free chlorine usually combines with an amine (ammonia or nitrogen) or other organic compounds to form combined chlorine compounds.

FREE OXYGEN FREE OXYGEN

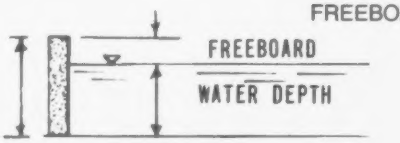
Molecular oxygen available for respiration by organisms. Molecular oxygen is the oxygen molecule, O_2, that is not combined with another element to form a compound.

FREE RESIDUAL CHLORINATION FREE RESIDUAL CHLORINATION

The application of chlorine or chlorine compounds to water or wastewater to produce a free available chlorine residual directly or through the destruction of ammonia (NH_3) or certain organic nitrogenous compounds.

FREEBOARD FREEBOARD

The vertical distance from the normal water surface to the top of the confining wall.



FRICTION LOSS FRICTION LOSS

The head lost by water flowing in a stream or conduit as the result of the disturbances set up by the contact between the moving water and its containing conduit and by intermolecular friction.

GASIFICATION (GAS-i-fi-KAY-shun) GASIFICATION

The conversion of soluble and suspended organic materials into gas during anaerobic decomposition. In clarifiers the resulting gas bubbles can become attached to the settled sludge and cause large clumps of sludge to rise and float on the water surface. In anaerobic sludge digesters, this gas is collected for fuel or disposed of using the waste gas burner.

GATE GATE

A movable watertight barrier for the control of a liquid in a waterway.

GRAB SAMPLE GRAB SAMPLE

A single sample of wastewater taken at neither a set time nor flow.

GRAVIMETRIC GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by *WEIGHING* a precipitate or residue of the sample.

GRIT GRIT

The heavy mineral material present in wastewater, such as sand, eggshells, gravel, and cinders.

GRIT REMOVAL GRIT REMOVAL

Grit removal is accomplished by providing an enlarged channel or chamber which causes the flow velocity to be reduced and allows the heavier grit to settle to the bottom of the channel where it can be removed.

GROWTH RATE GROWTH RATE

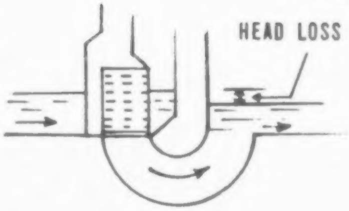
An experimentally determined constant to estimate the unit growth rate of bacteria while degrading organic wastes.

HEAD HEAD

A term used to describe the height or energy of water above a point. A head of water may be measured in either height (feet or meters) or pressure (pounds per square inch or kilograms per square centimeter). Also see DISCHARGE HEAD, DYNAMIC HEAD, STATIC HEAD, SUCTION HEAD, SUCTION LIFT and VELOCITY HEAD.

HEAD LOSS HEAD LOSS

An indirect measure of loss of energy or pressure. Flowing water will lose some of its energy when it passes through a pipe, bar screen, comminutor, filter or other obstruction. The amount of energy or pressure lost is called "head loss." Head loss is measured as the difference in elevation between the upstream water surface and the downstream water surface and may be expressed in feet or meters.



HEADER HEADER

A large pipe to which the ends of a series of smaller pipes are connected. Also called a "manifold."

HEADWORKS HEADWORKS

The facilities where wastewater enters a wastewater treatment plant. The headworks may consist of bar screens, comminutors, a wet well and pumps.

HEPATITIS HEPATITIS

Hepatitis is an acute viral infection of the liver. Yellow jaundice is one symptom of hepatitis.

HUMUS SLUDGE HUMUS SLUDGE

The sloughed particles of biomass from trickling filter media that are removed from the water being treated in secondary clarifiers.

HYDRAULIC GRADE LINE (HGL) HYDRAULIC GRADE LINE (HGL)

The surface or profile of water flowing in an open channel or a pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small tube connected to the pipe. To reduce the release of odors from wastewater, the water surface should be kept as smooth as possible.

HYDRAULIC LOADING HYDRAULIC LOADING

Hydraulic loading refers to the flows (MGD or cu m/day) to a treatment plant or treatment process. Detention times, surface loadings and weir overflow rates are directly influenced by flows.

HYDROGEN ION CONCENTRATION (H^+) HYDROGEN ION CONCENTRATION (H^+)

The weight of hydrogen ion in moles per liter of solution. Commonly expressed as the pH value, which is the logarithm of the reciprocal of the hydrogen-ion concentration.

$$pH = \log \frac{1}{(H^+)}$$

HYDROGEN SULFIDE (H_2S) HYDROGEN SULFIDE (H_2S)

Hydrogen sulfide is a gas with a rotten egg odor. This gas is produced under anaerobic conditions. Hydrogen sulfide is particularly dangerous because it dulls your sense of smell so that you don't notice it after you have been around it for a while and because the odor is not noticeable in high concentrations. The gas is very poisonous to your respiratory system, explosive, flammable and colorless.

HYDROLOGIC CYCLE (HI-dro-loj-ic) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement and runoff into rivers, streams and the ocean.

HYDROLYSIS (hi-DROL-e-sis) HYDROLYSIS

The addition of water to the molecule to break down complex substances into simpler ones.

HYDROSTATIC SYSTEM HYDROSTATIC SYSTEM

In a hydrostatic sludge removal system, the surface of the water in the clarifier is higher than the surface of the water in the sludge well or hopper. This difference in pressure head forces sludge from the bottom of the clarifier to flow through pipes to the sludge well or hopper.

HYGROSCOPIC (HI-grow-SKOP-ic) HYGROSCOPIC

A substance that absorbs or attracts moisture from the air.

HYPOCHLORINATION (hi-po-KLOR-i-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water or wastewater for the purpose of disinfection.

HYPOCHLORINATORS (hi-poe-KLOR-i-NAY-tors) HYPOCHLORINATORS

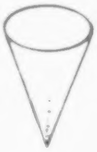
Chlorine pumps or devices used to feed chlorine solutions made from hypochlorites such as bleach (sodium hypochlorite) or calcium hypochlorite.

HYPOCHLORITE (hi-po-KLOR-ite) HYPOCHLORITE

Hypochlorite compounds contain chlorine and are used for disinfection. They are available as liquids or solids (powder, granules, and pellets) in barrels, drums, and cans.

IMHOFF CONE IMHOFF CONE

A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume of wastewater.



IMPELLER IMPELLER

A rotating set of vanes designed to impart rotation of a mass of fluid.

IMPELLER PUMP IMPELLER PUMP

Any pump in which the water is moved by the continuous application of power from some rotating mechanical source.

INCINERATION INCINERATION

The conversion of dewatered sludge cake by combustion (burning) to ash, carbon dioxide and water vapor.

INDICATOR (CHEMICAL) INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INDOLE (IN-dole) INDOLE

An organic compound (C_8H_7N) containing nitrogen which has an ammonia odor.

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The seepage of groundwater into a sewer system, including service connections. Seepage frequently occurs through defective or cracked pipes, pipe joints, connections or manhole walls.

INFLOW INFLOW

Water discharged into the sewer system from sources other than regular connections. This includes flow from yard drains, foundation drains and around manhole covers. Inflow differs from infiltration in that it is a direct discharge into the sewer rather than a leak in the sewer itself.

INFLUENT (IN-flu-ent) INFLUENT

Wastewater or other liquid — raw or partially treated — flowing *INTO* a reservoir, basin, treatment process, or treatment plant.

INHIBITORY SUBSTANCES INHIBITORY SUBSTANCES

Materials that kill or restrict the ability of organisms to treat wastes.

INOCULATE (in-NOCK-you-late) INOCULATE

To introduce a seed culture into a system.

INORGANIC WASTE INORGANIC WASTE

Waste material such as sand, salt, iron, calcium, and other mineral materials which are only slightly affected by the aciton of organisms. Inorganic wastes are chemical substances of mineral origin; whereas organic wastes are chemical substances usually of animal or plant origin. Also see NONVOLATILE MATTER.

INTERFACE INTERFACE

The common boundary layer between two fluids such as a gas (air) and a liquid (water) or a liquid (water) and another liquid (oil).

IONIC CONCENTRATION IONIC CONCENTRATION

The concentration of any ion in solution, generally expressed in moles per liter.

IONIZATION IONIZATION

The process of adding electrons to, or removing electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, and nuclear radiation can cause ionization.

JAR TEST JAR TEST

A laboratory procedure that simulates coagulation/flocculation with differing chemical doses. The purpose of the procedure is to *ESTIMATE* the minimum coagulant dose required to achieve certain water quality goals. Samples of water to be treated are placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of solids is observed. The lowest dose of chemicals that provides satisfactory settling is the dose used to treat the water.

JOULE (jewel) JOULE

A measure of energy, work or quantity of heat. One joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force.

KJELDAHL NITROGEN (KELL-doll) KJELDAHL NITROGEN

Organic and ammonia nitrogen.

LAUNDERS (LAWN-ders) LAUNDERS

Sedimentation tank effluent troughs.

LIMIT SWITCH LIMIT SWITCH

A device that regulates or controls the travel distance of a chain or cable.

LINEAL (LIN-e-al) LINEAL

The length in one direction of a line. For example, a board 12 feet long has 12 lineal feet in its length.

LIQUEFACTION (LICK-we-FACK-shun) LIQUEFACTION

The conversion of large solid particles of sludge into very fine particles which either dissolve or remain suspended in wastewater.

LOADING LOADING

Quantity of material applied to a device at one time.

M or MOLAR M or MOLAR

A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A 1*M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MBAS MBAS

Methylene **B**lue **A**ctive **S**ubstance. Another name for surfactants, or surface active agents, is methylene blue active substances. The determination of surfactants is accomplished by measuring the color change in a standard solution of methylene blue dye.

MCRT MCRT

Mean **C**ell **R**esidence **T**ime, days. An expression of the average time that a microorganism will spend in the activated sludge process.

$$\text{MCRT, days} = \frac{\text{Solids in Activated Sludge Process, lbs}}{\text{Solids Removed from Process, lbs/day}}$$

MLSS MLSS

Mixed **L**iquor **S**uspended **S**olids, mg/*L*. Suspended solids in the mixed liquor of an aeration tank.

MLVSS MLVSS

Mixed **L**iquor **V**olatile **S**uspended **S**olids, mg/*L*. The organic or volatile suspended solids in the mixed liquor of an aeration tank. This volatile portion is used as a measure or indication of the microorganisms present.

MPN (EM-PEA-EN) MPN

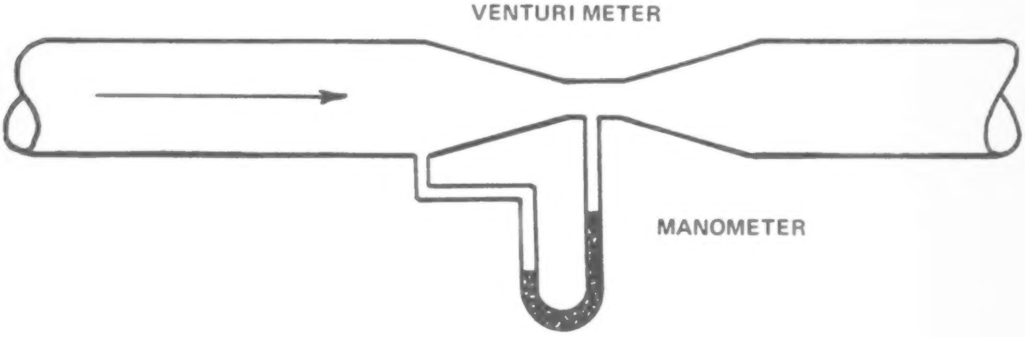
MPN is the **M**ost **P**robable **N**umber of coliform-group organisms per unit volume. Expressed as a density or population of organisms per 100 ml.

MANIFOLD MANIFOLD

A large pipe to which the ends of a series of smaller pipes are connected. Also called a "header."

MANOMETER (man-NAH-met-ter) MANOMETER

An instrument for measuring pressure. Usually a glass tube filled with a liquid and used to measure the difference in pressure across a flow-measuring device such as an orifice or Venturi meter. The instrument used to measure blood pressure is a type of manometer.



MASKING AGENTS MASKING AGENTS

Substances used to cover up or disguise unpleasant odors. Liquid masking agents are dripped into the wastewater, sprayed into the air, or evaporated (using heat) with the unpleasant fumes or odors and then discharged into the air by blowers to make an undesirable odor less noticeable.

MEAN CELL RESIDENCE TIME (MCRT) MEAN CELL RESIDENCE TIME (MCRT)

An expression of the average time that a microorganism will spend in the activated sludge process.

$$\text{MCRT, days} = \frac{\text{Solids in Activated Sludge Process, lbs}}{\text{Solids Removed from Process, lbs/day}}$$

MECHANICAL AERATION MECHANICAL AERATION

The use of machinery to mix air and water so that oxygen can be absorbed into the water. Some examples are: paddle wheels, mixers, or rotating brushes to agitate the surface of an aeration tank; pumps to create fountains; and pumps to discharge water down a series of steps forming falls or cascades.

MEDIA MEDIA

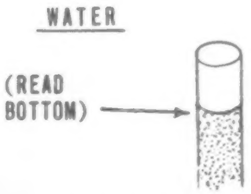
The material in a trickling filter on which slime organisms grow. As settled wastewater trickles over the media, slime organisms remove certain types of wastes thereby partially treating the wastewater. Also the material in a rotating biological contactor or in a gravity or pressure filter.

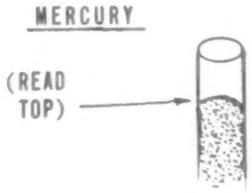
MEDIAN MEDIAN

The middle measurement or value. When several measurements are ranked by magnitude (largest to smallest), half of the measurements will be larger and half will be smaller.

MENISCUS (meh-NIS-cuss) MENISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.





MERCAPTANS (mer-CAP-tans) MERCAPTANS

Compounds containing sulfur which have an extremely offensive skunk odor.

MESOPHILIC BACTERIA (mess-O-FILL-lick) MESOPHILIC BACTERIA

Medium temperature bacteria. A group of bacteria that grow and thrive in a moderate temperature range between 68°F (20°C) and 113°F (45°C). The optimum temperature range for these bacteria in anaerobic digestion is 85°F (30°C) to 100°F (38°C).

MICRON (MY-kron) MICRON

A unit of length. One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

MICROORGANISMS (micro-ORGAN-is-sums) MICROORGANISMS

Very small organisms that can be seen only through a microscope. Some microorganisms use the wastes in wastewater for food and thus remove or alter much of the undesirable matter.

MICROSCREEN MICROSCREEN

A device with a fabric straining media with openings usually between 2 and 60 microns. The fabric is wrapped around the outside of a rotating drum. Wastewater enters the open end of the drum and flows out through the rotating screen cloth. At the highest point of the drum, the collected solids are backwashed by high-pressure water jets into a trough located within the drum.

MILLIGRAMS PER LITER, mg/*L* (MILL-i-GRAMS per LEET-er) MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/*L* is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams; and if it contains 10 milligrams of dissolved oxygen, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of oxygen per million parts of water, or 10 parts per million (10 ppm).

MILLIMICRON (MILL-e-MY-cron) MILLIMICRON

One thousandth of a micron or a millionth of a millimeter.

MIXED LIQUOR MIXED LIQUOR

When the activated sludge in an aeration tank is mixed with primary effluent or the raw wastewater and return sludge, this mixture is then referred to as mixed liquor as long as it is in the aeration tank. Mixed liquor also may refer to the contents of mixed aerobic or anaerobic digesters.

MIXED LIQUOR SUSPENDED SOLIDS (MLSS) MIXED LIQUOR SUSPENDED SOLIDS(MLSS)

Suspended solids in the mixed liquor of an aeration tank.

MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS) MIXED LIQUOR VOLATILE SUSPENDED SOLIDS (MLVSS)

The organic or volatile suspended solids in the mixed liquor of an aeration tank.

MOLECULAR OXYGEN MOLECULAR OXYGEN

The oxygen molecule, O_2, that is not combined with another element to form a compound.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-kule) MOLECULE

A molecule is the smallest portion of an element or compound that still retains or exhibits all the properties of the substance.

MOTILE (MO-till) MOTILE

Motile organisms exhibit or are capable of movement.

MOVING AVERAGE MOVING AVERAGE

To calculate the moving average for the last 7 days, add up the values for the last 7 days and divide by 7. Each day add the most recent day to the sum of values and subtract the oldest value. By using the 7-day moving average, each day of the week is always represented in the calculations.

MUFFLE FURNACE MUFFLE FURNACE

A small oven capable of reaching temperatures up to 600°C. Muffle furnaces are used in laboratories for burning or incinerating samples to determine the amounts of volatile solids and/or fixed solids in samples of wastewater.

MULTI-STAGE PUMP MULTI-STAGE PUMP

A pump that has more than one impeller. A single-stage pump has one impeller.

N or NORMAL N or NORMAL

A normal solution contains one gram equivalent weight of a reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NPDES PERMIT NPDES PERMIT

National **P**ollutant **D**ischarge **E**limination **S**ystem permit is the regulatory agency document designed to control all discharges of pollutants from point sources into U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

NEUTRALIZATION (new-trall-i-ZAY-shun) NEUTRALIZATION

Addition of an acid or alkali (base) to a liquid to cause the pH of the liquid to move towards a neutral pH of 7.0.

NITRIFICATION (NYE-tri-fi-KAY-shun) NITRIFICATION

A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the "nitrification stage" (first-stage BOD is called the "carbonaceous stage").

NITRIFYING BACTERIA NITRIFYING BACTERIA

Bacteria that change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate).

NITROGENOUS (nye-TROG-en-ous) NITROGENOUS

Nitrogenous compounds contain nitrogen.

NOMOGRAM NOMOGRAM

A chart or diagram containing three or more scales used to solve problems with three or more variables instead of using mathematical formulas.

NONCORRODIBLE NONCORRODIBLE

A material that resists corrosion and will not be eaten away by wastewater or chemicals in wastewater.

NONSPARKING TOOLS NONSPARKING TOOLS

These tools will not produce a spark during use.

NONVOLATILE MATTER NONVOLATILE MATTER

Material such as sand, salt, iron, calcium, and other mineral materials which are only slightly affected by the action of organisms. Volatile materials are chemical substances usually of animal or vegetable origin. Also see INORGANIC WASTE.

NUTRIENT CYCLE NUTRIENT CYCLE

The transformation or change of a nutrient from one form to another until the nutrient has returned to the original form, thus completing the cycle. The cycle may take place under either aerobic or anaerobic conditions.

NUTRIENTS NUTRIENTS

Substances which are required to support living plants and organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen and phosphorus. Nitrogen and phosphorus are difficult to remove from wastewater by conventional treatment processes because they are water soluble and tend to recycle. Also see NUTRIENT CYCLE.

O & M MANUAL (**O**peration and **M**aintenance Manual) O & M MANUAL

A manual which outlines procedures for operators to follow to operate and maintain a specific wastewater treatment plant and the equipment in the plant.

OSHA OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and treatment plant operators. It regulates the design, construction, operation and maintenance of industrial plants and wastewater treatment plants. The Act does not apply directly to municipalities at present (1980), *EXCEPT* in those states that have approved plans and have asserted jurisdiction under Section 18 of the OSHA Act. However, wastewater treatment plants have come under stricter regulation in all phases of activity as a result of OSHA standards.

OBLIGATE AEROBES OBLIGATE AEROBES

Bacteria that must have molecular (dissolved) oxygen (DO) to reproduce.

ODOR PANEL ODOR PANEL

A group of people used to measure odors.

OFFSET OFFSET

The difference between the actual value and the desired value (or set point) characteristic of proportional controllers that do not incorporate reset action. Also called DROOP.

OLFACTOMETER (ol-FACT-tom-meter) OLFACTOMETER

A device used to measure odors in the field by diluting odors with odor-free air.

ORGANIC WASTE ORGANIC WASTE

Waste material which comes mainly from animal or plant sources. Organic waste generally can be consumed by bacteria and other small organisms. Inorganic wastes are chemical substances of mineral origin.

ORGANISM ORGANISM

Any form of animal or plant life. Also see BACTERIA.

ORIFICE (OR-uh-fiss) ORIFICE

An opening in a plate, wall or partition. In a trickling filter distributor, the wastewater passes through an orifice to the surface of the filter media. An orifice flange set in a pipe consists of a slot or hole smaller than the pipe diameter. The difference in pressure in the pipe above and at the orifice may be related to flow in the pipe.

ORTHOTOLIDINE (or-tho-TOL-i-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This method is no longer approved for tests of effluent chlorine residual.

OVERFLOW RATE OVERFLOW RATE

One of the guidelines for the design of settling tanks and clarifiers in treatment plants.

$$\text{Overflow Rate, gpd/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

OXIDATION (ox-i-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In wastewater treatment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant) and used as a qualitative measure of the state of oxidation in wastewater treatment systems.

OXIDIZED ORGANICS OXIDIZED ORGANICS

Organic materials that have been broken down in a biological process. Examples of these materials are carbohydrates and proteins that are broken down to simple sugars.

OXIDIZING AGENT OXIDIZING AGENT

An oxidizing agent is any substance, such as oxygen (O_2) and chlorine (Cl_2), that can add (take on) electrons. When oxygen or chlorine is added to wastewater, organic substances are oxidized. These oxidized organic substances are more stable and less likely to give off odors or to contain disease bacteria. The opposite of REDUCING AGENT.

OZONATION (O-zoe-NAY-shun) OZONATION

The application of ozone to water, wastewater, or air, generally for the purposes of disinfection or odor control.

PACKAGE TREATMENT PLANT PACKAGE TREATMENT PLANT

A small wastewater treatment plant often fabricated at the manufacturer's factory, hauled to the site, and installed as one facility. The package may be either a small primary or a secondary wastewater treatment plant.

PARALLEL OPERATION PARALLEL OPERATION

When wastewater being treated is split and a portion flows to one treatment unit while the remainder flows to another similar treatment unit. Also see SERIES OPERATION.

PARASITIC BACTERIA (PAIR-a-SIT-tick) PARASITIC BACTERIA

Parasitic bacteria are those bacteria which normally live off another living organism, known as the "host."

PATHOGENIC ORGANISMS (path-o-JEN-ick) PATHOGENIC ORGANISMS

Bacteria, viruses or cysts which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do *NOT* cause disease and which are *NOT* called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

PERCENT SATURATION **PERCENT SATURATION**

The amount of a substance that is dissolved in a solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Sub. that is Dissolved} \times 100\%}{\text{Amount that Could be Dissolved in Solution}}$$

PERCOLATION (PURR-ko-LAY-shun) **PERCOLATION**

The movement or flow of water through soil or rocks.

PERISTALTIC PUMP (peri-STALL-tick) **PERISTALTIC PUMP**

A type of positive displacement pump.

pH (PEA-A-ch) **pH**

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration.

$$\text{pH} = \text{Log}\,\frac{1}{(\text{H}^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 is neutral. Nautral waters usually have a pH between 6.5 and 8.5.

PHENOL (FEE-noll) **PHENOL**

An organic compound that is a derivative of benzene.

PHENOLPHTHALEIN ALKALINITY **PHENOLPHTHALEIN ALKALINITY**

A measure of the hydroxide ions plus one half of the normal carbonate ions in aqueous suspension. Measured by the amount of sulfuric acid required to bring the water to a pH value of 8.3, as indicated by a change in color of phenolphthalein. It is expressed in milligrams per liter of calcium carbonate.

PHOTOSYNTHESIS (foto-SIN-the-sis) **PHOTOSYNTHESIS**

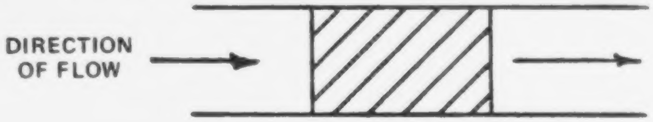
A process in which organisms with the aid of chlorophyll (green plant enzyme) convert carbon dioxide and inorganic substances to oxygen and additional plant material, utilizing sunlight for energy. All green plants grow by this process.

PHYSICAL WASTE TREATMENT PROCESS **PHYSICAL WASTE TREATMENT PROCESS**

Physical waste treatment processes include use of racks, screens, comminutors, and clarifiers (sedimentation and flotation). Chemical or biological reactions are not an important part of a physical treatment process.

PLUG FLOW **PLUG FLOW**

A type of flow that occurs in tanks, basins or reactors when a slug of wastewater moves through a tank without ever dispersing or mixing with the rest of the wastewater flowing through the tank.



PLUG FLOW

POLLUTION **POLLUTION**

Any change in the natural state of water which interferes with its beneficial reuse or causes failure to meet water-quality requirements.

POLYELECTROLYTE (POLY-electro-light) **POLYELECTROLYTE**

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polyelectrolytes may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polymer."

POLYMER (POLY-mer) **POLYMER**

A high-molecular-weight substance that is formed by either a natural or synthetic process. Natural polymers may be of biological origin or derived from starch products, cellulose derivatives, and alignates. Synthetic polymers consist of simple substances that have been made into complex, high-molecular-weight substances. Often called a "polyelectrolyte."

POLYSACCHARIDE (polly-SAC-a-ride) **POLYSACCHARIDE**

A carbohydrate such as starch, insulin or cellulose.

PONDING PONDING

A condition occurring on trickling filters when the hollow spaces (voids) become plugged to the extent that water passage through the filter is inadequate. Ponding may be the result of excessive slime growths, trash, or media breakdown.

POPULATION EQUIVALENT POPULATION EQUIVALENT

A means of expressing the strength of organic material in wastewater. In a domestic wastewater system, microorganisms use up about 0.2 pounds of oxygen per day for each person using the system (as measured by the standard BOD test).

$$\text{Pop. Equiv., persons} = \frac{\text{Flow, MGD} \times \text{BOD, mg}/L \times 8.34\ \text{lbs/gal}}{0.2\ \text{lbs BOD/day/person}}$$

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant discharge or effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-ta-bl) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered safe for domestic consumption.

PRE-AERATION PRE-AERATION

The addition of air at the initial stages of treatment to freshen the wastewater, remove gases, add oxygen, promote flotation of grease, and aid coagulation.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for odor and corrosion control. Also applied to aid disinfection, to reduce plant BOD load, to aid in settling, to control foaming in Imhoff units and to help remove oil.

PRECIPITATE (pre-SIP-i-TATE) PRECIPITATE

To separate (a substance) out in solid form from a solution, as by the use of a reagent. The substance precipitated.

PRECOAT PRECOAT

Application of a free-draining, non-cohesive material such as diatomaceous earth to a filtering media. Precoating reduces the frequency of media washing and facilitates cake discharge.

PRETREATMENT PRETREATMENT

The removal of metal, rocks, rags, sand, eggshells, and similar materials which may hinder the operation of a treatment plant. Pretreatment is accomplished by using equipment such as racks, bar screens, comminutors, and grit removal systems.

PRIMARY TREATMENT PRIMARY TREATMENT

A wastewater treatment process that takes place in a rectangular or circular tank and allows those substances in wastewater that readily settle or float to be separated from the water being treated.

PROCESS VARIABLE PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled.

PROTEINACEOUS (PRO-ten-NAY-shus) PROTEINACEOUS

Materials containing proteins which are organic compounds containing nitrogen.

PROTOZOA (pro-toe-ZOE-ah) PROTOZOA

A group of microscopic animals (usually single-celled) that sometimes cluster into colonies.

PRUSSIAN BLUE PRUSSIAN BLUE

A paste or liquid used to show a contact area. Used to determine if gate valve seats fit properly.

PSYCHROPHILIC BACTERIA (sy-kro-FILL-lick) PSYCHROPHILIC BACTERIA

Cold temperature bacteria. A group of bacteria that grow and thrive in temperatures below 68°F (20°C).

PUG MILL PUG MILL

A mechanical device with rotating paddles or blades that is used to mix and blend different materials together.

PURGE PURGE

To remove a gas or vapor from a vessel, reactor or confined space.

PUTREFACTION (PEW-tree-FACK-shun) PUTREFACTION

Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

PUTRESCIBLE (pew-TRES-uh-bull) PUTRESCIBLE

Material that will decompose under anaerobic conditions and produce nuisance odors.

PYROMETER (pie-ROM-uh-ter) PYROMETER

An apparatus used to measure high temperatures.

RAS RAS

Return **A**ctivated **S**ludge, mg/*L*. Settled activated sludge that is collected in the secondary clarifier and returned to the aeration basin to mix with incoming raw or primary settled wastewater.

RABBLING RABBLING

The process of moving or plowing the material inside a furnace by using the center shaft and rabble arms.

RACK RACK

Evenly spaced parallel metal bars or rods located in the influent channel to remove rags, rocks, and cans from wastewater.

RAW WASTEWATER RAW WASTEWATER

Plant influent or wastewater before any treatment.

REAGENT (re-A-gent) REAGENT

A substance which takes part in a chemical reaction and is used to measure, detect, or examine other substances.

RECALCINATION (re-CAL-si-NAY-shun) RECALCINATION

A lime-recovery process in which the calcium carbonate in sludge is converted to lime by heating at 1800°F (980°C).

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled through the water being treated to lower the pH.

RECEIVING WATER RECEIVING WATER

A stream, river, lake or ocean into which treated or untreated wastewater is discharged.

RECHARGE RATE RECHARGE RATE

Rate at which water is added beneath the ground surface to replenish or recharge groundwater.

RECIRCULATION RECIRCULATION

The return of part of the effluent from a treatment process to the incoming flow.

RECLAMATION RECLAMATION

The operation or process of changing the condition or characteristics of water so that improved uses can be achieved.

RECYCLE RECYCLE

The use of water or wastewater within (internally) a facility before it is discharged to a treatment system. Also see REUSE.

REDUCING AGENT REDUCING AGENT

A reducing agent is any substance, such as the chloride ion (Cl^-) and sulfide ion (S^{-2}), that can give up electrons. The opposite of OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions in wastewater, sulfate compounds or elemental sulfur are reduced to odor-producing hydrogen sulfide (H_2S) or the sulfide ion (S^{-2}). The opposite of OXIDATION.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to a liquid. For example, a condensation of chlorine gas returning to the liquid form.

REFRACTORY MATERIALS (re-FRACK-tory) REFRACTORY MATERIALS

Material difficult to remove entirely from wastewater such as nutrients, color, taste- and odor-producing substances and some toxic materials.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water identical in content to that in the larger body of material or water being sampled.

RESIDUAL CHLORINE RESIDUAL CHLORINE

Residual chlorine is the amount of chlorine remaining after a given contact time and under specific conditions.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

RETENTION TIME RETENTION TIME

The time water, sludge or solids are retained or held in a clarifier or sedimentation tank. See DETENTION TIME.

RETURN ACTIVATED SLUDGE (RAS) RETURN ACTIVATED SLUDGE (RAS)

Settled activated sludge that is collected in the secondary clarifier and returned to the aeration basin to mix with incoming raw or primary settled wastewater.

REUSE REUSE

The use of water or wastewater after it has been discharged and then withdrawn by another user. Also see RECYCLE.

RIPRAP RIPRAP

Broken stones, boulders, or other materials placed compactly or irregularly on levees or dikes for the protection of earth surfaces against the erosive action of waves.

RISING SLUDGE RISING SLUDGE

Rising sludge occurs in the secondary clarifiers of activated sludge plants when the sludge settles to the bottom of the clarifier, is compacted, and then starts to rise to the surface, usually as a result of denitrification.

ROTAMETER ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a calibrated tube. Inside the tube is a small ball or a bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind the middle of the ball or the top of the float.

ROTARY PUMP ROTARY PUMP

A type of displacement pump consisting essentially of elements rotating in a pump case which they closely fit. The rotation of these elements alternately draws in and discharges the water being pumped. Such pumps act with neither suction nor discharge valves, operate at almost any speed, and do not depend on centrifugal forces to lift the water.

ROTIFERS (ROE-ti-fers) ROTIFERS

Microscopic animals characterized by short hairs on their front end.

ROTOR ROTOR

The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts of the machine (stator).

SAR (**S**odium **A**dsorption **R**atio) SAR

This ratio expresses the relative activity of sodium ions in the exchange reactions with soil. The ratio is defined as follows:

$$\text{SAR} = \frac{\text{Na}}{\left[\frac{1}{2}(\text{Ca} + \text{Mg})\right]^{1/2}}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water.

$$\text{Na, meq}/L = \frac{\text{Na, mg}/L}{23.0 \text{ mg/meq}} \qquad \text{Ca, meq}/L = \frac{\text{Ca, mg}/L}{20.0 \text{ mg/meq}}$$

$$\text{Mg, meq}/L = \frac{\text{Mg, mg}/L}{12.15 \text{ mg/meq}}$$

SCFM SCFM

Cubic **F**eet of air per **M**inute at **S**tandard conditions of temperature, pressure and humidity.

SVI (Sludge Volume Index) SVI

This is a test used to indicate the settling ability of activated sludge (aerated solids) in the secondary clarifier. The test is a measure of the volume of sludge compared with its weight. Allow the sludge sample from the aeration tank to settle for 30 minutes. Then calculate SVI by dividing the volume (ml) of wet settled sludge by the weight (mg) of that sludge after it has been dried. Sludge with an SVI of one hundred or greater will not settle as readily as desirable because it is as light as or lighter than water.

$$\text{SVI} = \frac{\text{Wet Settled Sludge, ml} \times 1000}{\text{Dried Sludge Solids, mg}}$$

SANITARY SEWER (SAN-eh-tare-ee SUE-er) SANITARY SEWER

A sewer intended to carry wastewater from homes, businesses, and industries. Storm water runoff should be collected and transported in a separate system of pipes.

SAPROPHYTIC ORGANISMS (SAP-pro-FIT-tik) SAPROPHYTIC ORGANISMS

Organisms living on dead or decaying organic matter. They help natural decomposition of the organic solids in wastewater.

SCREEN SCREEN

A device used to retain or remove suspended or floating objects in wastewater. The screen has openings that are generally uniform in size. It retains or removes objects larger than the openings. A screen may consist of bars, rods, wires, gratings, wire mesh, or perforated plates.

SEALING WATER SEALING WATER

Water used to prevent wastewater or dirt from reaching moving parts. Sealing water is at a higher pressure than the wastewater it is keeping out of a mechanical device.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded secchi disc reading.

SECONDARY TREATMENT SECONDARY TREATMENT

A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated. Usually the process follows primary treatment by sedimentation. The process commonly is a type of biological treatment process followed by secondary clarifiers that allow the solids to settle out from the water being treated.

SEED SLUDGE SEED SLUDGE

In wastewater treatment, seed, seed culture or seed sludge refers to a mass of sludge which contains very concentrated populations of microorganisms. When a seed sludge is mixed with the wastewater or sludge being treated, the process of biological decomposition takes place more rapidly.

SEIZING SEIZING

Seizing occurs when an engine overheats and a component expands to the point where the engine will not run. Also called "freezing."

SEPTIC (SEP-tick) SEPTIC

This condition is produced by anaerobic bacteria. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

SEPTICITY (sep-TIS-it-tee) SEPTICITY

Septicity is the condition in which organic matter decomposes to form foul-smelling products associated with the absence of free oxygen. If severe, the wastewater turns black, gives off foul odors, contains little or no dissolved oxygen and creates a heavy oxygen demand.

SERIES OPERATION SERIES OPERATION

When wastewater being treated flows through one treatment unit and then flows through another similar treatment unit. Also see PARALLEL OPERATION.

SET POINT SET POINT

The position at which the control or controller is set. This is the same as the desired value of the process variable.

SEWAGE SEWAGE

The used water and solids from homes that flow to a treatment plant. The preferred term is wastewater.

SHEAR PIN SHEAR PIN

A straight pin with a groove around the middle that will weaken the pin and cause it to fail when a certain load or stress is exceeded. The purpose of the pin is to protect equipment from damage due to excessive loads or stresses.

SHOCK LOAD SHOCK LOAD

The arrival at a plant of a waste which is toxic to organisms in sufficient quantity or strength to cause operating problems. Possible problems include odors and sloughing off of the growth or slime on the trickling-filter media. Organic or hydraulic overloads also can cause a shock load.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or ponds when some of the water or wastewater travels faster than the rest of the flowing water.

SHREDDING SHREDDING

Comminution. A mechanical treatment process which cuts large pieces of wastes into smaller pieces so they won't plug pipes or damage equipment. *SHREDDING* and *COMMINUTION* usually mean the same thing.

SIDESTREAM SIDESTREAM

Wastewater flows that develop from other storage or treatment facilities. This wastewater may or may not need additional treatment.

SIGNIFICANT FIGURE SIGNIFICANT FIGURE

The number of accurate numbers in a measurement. If the distance between two points is measured to the nearest hundredth and recorded as 238.41 feet, the measurement has five significant figures.

SINGLE-STAGE PUMP SINGLE-STAGE PUMP

A pump that has only one impeller. A multi-stage pump has more than one impeller.

SKATOLE (SKATE-tole) SKATOLE

An organic compound (C_9H_9N) containing nitrogen which has a fecal odor.

SLAKE SLAKE

To become mixed with water so that a true chemical reaction takes place, such as in the slaking of lime.

SLOUGHINGS (SLUFF-ings) SLOUGHINGS

Trickling-filter slimes that have been washed off the filter media. They are generally quite high in BOD and will lower effluent quality unless removed.

SLUDGE (sluj) SLUDGE

The settleable solids separated from liquids during processing or the deposits of foreign materials on the bottoms of streams or other bodies of water.

SLUDGE AGE SLUDGE AGE

A measure of the length of time a particle of suspended solids has been undergoing aeration in the activated sludge process.

$$\text{Sludge Age, days} = \frac{\text{Suspended Solids Under Aeration, lbs or kg}}{\text{Suspended Solids Added, lbs/day or kg/day}}$$

SLUDGE DENSITY INDEX (SDI) SLUDGE DENSITY INDEX (SDI)

This test is used in a way similar to the Sludge Volume Index (SVI) to indicate the settleability of a sludge in a secondary clarifier or effluent. SDI = 100/SVI. Also see SLUDGE VOLUME INDEX (SVI).

SLUDGE DIGESTION SLUDGE DIGESTION

The process of changing organic matter in sludge into a gas or a liquid or a more stable solid form. These changes take place as microorganisms feed on sludge in anaerobic (more common) or aerobic digesters.

SLUDGE GASIFICATION SLUDGE GASIFICATION

A process in which soluble and suspended organic matter are converted into gas by anaerobic decomposition. The resulting gas bubbles can become attached to the settled sludge and cause large clumps of sludge to rise and float on the water surface.

SLUDGE VOLUME INDEX (SVI) SLUDGE VOLUME INDEX (SVI)

This is a test used to indicate the settling ability of activated sludge (aerated solids) in the secondary clarifier. The test is a measure of the volume of sludge compared with its weight. Allow the sludge sample from the aeration tank to settle for 30 minutes. Then calculate SVI by dividing the volume (ml) of wet settled sludge by the weight (mg) of that sludge after it has been dried. Sludge with an SVI of one hundred or greater will not settle as readily as desirable because it is as light as or lighter than water.

$$\text{SVI} = \frac{\text{Wet Settled Sludge, ml} \times 1000}{\text{Dried Sludge Solids, mg}}$$

SLUDGE-VOLUME RATIO (SVR) SLUDGE-VOLUME RATIO (SVR)

The volume of sludge blanket divided by the daily volume of sludge pumped from the thickener.

SLUGS SLUGS

Intermittent releases or discharges of industrial wastes.

SLURRY (SLUR-e) SLURRY

A thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SODIUM ADSORPTION RATIO (SAR) SODIUM ABSORPTION RATIO (SAR)

This ratio expresses the relative activity of sodium ions in the exchange reactions with soil. The ratio is defined as follows:

$$\text{SAR} = \frac{\text{Na}}{[\frac{1}{2}(\text{Ca} + \text{Mg})]^{\frac{1}{2}}}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water.

$$\text{Na, meq}/L = \frac{\text{Na, mg}/L}{23.0 \text{ mg/meq}} \qquad \text{Ca, meq}/L = \frac{\text{Ca, mg}/L}{20.0 \text{ mg/meq}}$$

$$\text{Mg, meq}/L = \frac{\text{Mg, mg}/L}{12.15 \text{ mg/meq}}$$

SOFTWARE PROGRAMS SOFTWARE PROGRAMS

Computer programs designed and written to monitor and control wastewater treatment processes or other processes.

SOLUBLE BOD SOLUBLE BOD

Soluble BOD is the BOD of water that has been filtered in the standard suspended solids test.

SOLUTE SOLUTE

The substance dissolved in a solution. A solution is made up of the solvent and the solute.

SOLUTION SOLUTION

A liquid mixture of dissolved substances. In a solution it is impossible to see all the separate parts.

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle or substance in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Wastewater particles usually have a specific gravity of 0.5 to 2.5.

SPLASH PAD SPLASH PAD

A structure made of concrete or other durable material to protect bare soil from erosion by splashing or falling water.

STABILIZE STABILIZE

To convert to a form that resists change. Organic material is stabilized by bacteria which convert the material to gases and other relatively inert substances. Stabilized organic material generally will not give off obnoxious odors.

STABILIZED WASTE STABILIZED WASTE

A waste that has been treated or decomposed to the extent that, if discharged or released, its rate and state of decomposition would be such that the waste would not cause a nuisance or odors.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

(1) To compare with a standard. In wet chemistry, to find out the exact strength of a solution by comparing with a standard of known strength. This information is used to adjust the strength by adding more water or more of the substance dissolved. (2) To compare an instrument or device with a standard. This helps you to adjust the instrument so that it reads accurately or to prepare a scale, graph or chart that is accurate.

STASIS (STAY-sis) STASIS

Stagnation or inactivity of the life processes within organisms.

STATIC HEAD STATIC HEAD

When water is not moving, the distance (in feet or meters) from a point to the water surface.

STATOR STATOR

That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts.

STEP-FEED AERATION STEP-FEED AERATION

Step-feed aeration is a modification of the conventional activated sludge process. In step aeration, primary effluent enters the aeration tank at several points along the length of the tank, rather than all of the primary effluent entering at the beginning or head of the tank and flowing through the entire tank.

STERILIZATION (star-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all living microorganisms, including pathogenic and saprophytic bacteria, vegetative forms and spores. Compare with DISINFECTION.

STETHOSCOPE STETHOSCOPE

An instrument used to magnify sounds and convey them to the ear.

STOP LOG STOP LOG

A log or board in an outlet box or device used to control the water level in ponds.

STORM SEWER STORM SEWER

A separate sewer that carries runoff from storms, surface drainage, and street wash, but does not include domestic and industrial wastes.

STRIPPED GASES STRIPPED GASES

Gases that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed or tumbled over media.

STRIPPED ODORS STRIPPED ODORS

Odors that are released from a liquid by bubbling air through the liquid or by allowing the liquid to be sprayed and/or tumbled over media.

STUCK STUCK

Not working. A stuck digester does not decompose organic matter properly. The digester is characterized by low gas production, high volatile acid to alkalinity relationship, and poor liquid-solids separation. A digester in a stuck condition is sometimes called a "sour" or "upset" digester.

SUCTION HEAD SUCTION HEAD

The *POSITIVE* pressure (in feet (meters) or pounds per square inch (kilograms per square centimeter)) on the suction side of a pump. The pressure can be measured from the center line of the pump *UP TO* the elevation of the hydraulic grade line on the suction side of the pump.

SUCTION LIFT SUCTION LIFT

The *NEGATIVE* pressure (in feet (meters) or inches (centimeters) of mercury vacuum) on the suction side of the pump. The pressure can be measured from the center line of the pump *DOWN TO* the elevation of the hydraulic grade line on the suction side of the pump.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or to the primary clarifier.

SURFACE LOADING SURFACE LOADING

Surface loading is calculated by dividing the flow into a sedimentation tank or a clarifier by the surface area of the unit.

$$\text{Surface Loading, gpd/sq ft} = \frac{\text{Flow, gpd}}{\text{Surface Area, sq ft}}$$

SURFACTANT SURFACTANT

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

SUSPENDED SOLIDS SUSPENDED SOLIDS

(1) Solids that either float on the surface or are suspended in water, wastewater, or other liquids, and which are largely removable by laboratory filtering. (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER* and referred to as Total Suspended Solids Dried at 103-105°C.

TOC TOC

Total **O**rganic **C**arbon. TOC measures the amount of organic carbon in water.

TARE WEIGHT TARE WEIGHT

The weight of an empty weighing dish or container.

TERTIARY TREATMENT (TER-she-AIR-ee) TERTIARY TREATMENT

Any process of water renovation that upgrades treated wastewater to meet specific reuse requirements. May include general cleanup of water or removal of specific parts of wastes insufficiently removed by conventional treatment processes. Typical processes include chemical treatment and pressure filtration. Also called ADVANCED WASTE TREATMENT.

THERMOPHILIC BACTERIA (thermo-FILL-lick) THERMOPHILIC BACTERIA

Hot temperature bacteria. A group of bacteria that grow and thrive in temperatures above 113°F (45°C). The optimum temperature range for these bacteria in anaerobic decomposition is 120°F (49°C) to 135°F (57°C).

THIEF HOLE THIEF HOLE

A digester sampling well.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a sample (gas or water) that can just be detected after successive odorless (gas or water) dilutions.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical solution to completion of the reaction as signaled by the end point.

TOTAL DYNAMIC HEAD (TDH) TOTAL DYNAMIC HEAD (TDH)

When a pump is lifting or pumping water, the vertical distance (in feet or meters) from the elevation of the energy grade line on the suction side of the pump to the elevation of the energy grade line on the discharge side of the pump.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

TOTALIZER TOTALIZER

A device that continuously sums or adds the flow into a plant in gallons or million gallons or some other unit of measurement.

TOXIC (TOX-ick) TOXIC

Poisonous.

TOXICITY (tox-IS-it-tee) TOXICITY

A condition which may exist in wastes and will inhibit or destroy the growth or function of certain organisms.

TRANSPIRATION (TRAN-spear-RAY-shun) TRANSPIRATION

The process by which water vapor is lost to the atmosphere from living plants.

TRICKLING FILTER TRICKLING FILTER

A treatment process in which the wastewater trickles over media that provide the opportunity for the formation of slimes or biomass which contain organisms that feed upon and remove wastes from the water treated.

TRICKLING-FILTER MEDIA TRICKLING-FILTER MEDIA

Rocks or other durable materials that make up the body of the filter. Synthetic (manufactured) media have been used successfully.

TRUNK SEWER TRUNK SEWER

A sewer that receives wastewater from many tributary branches or sewers and serves a large territory and contributing population.

TURBID TURBID

Having a cloudy or muddy appearance.

TURBIDIMETER TURBIDIMETER

See TURBIDITY METER.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY METER TURBIDITY METER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

TWO-STAGE FILTERS TWO-STAGE FILTERS

Two filters are used. Effluent from the first filter goes to the second filter, either directly or after passing through a clarifier.

ULTRAFILTRATION ULTRAFILTRATION

A membrane filter process used for the removal of organic compounds in an aqueous (watery) solution.

UPSET UPSET

An upset digester does not decompose organic matter properly. The digester is characterized by low gas production, high volatile acid/alkalinity relationship, and poor liquid-solids separation. A digester in an upset condition is sometimes called a "sour" or "stuck" digester.

VECTOR VECTOR

An insect or other organism capable of transmitting germs or other agents of disease.

VELOCITY HEAD VELOCITY HEAD

A vertical height (in feet or meters) equal to the square of the velocity of flowing water divided by twice the acceleration due to gravity ($V^2/2g$).

VOLATILE (VOL-a-til) VOLATILE

A volatile substance is one that is capable of being evaporated or changed to a vapor at relatively low temperatures.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperature.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water, wastewater, or other liquids that are lost on ignition of the dry solids at 550°C.

VOLUMETRIC VOLUMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample *BY DETERMINING THE VOLUME* of titrant or liquid reagent needed to complete particular reactions.

VOLUTE (vol-LOOT) VOLUTE

The spiral-shaped casing which surrounds a pump, blower, or turbine impeller and collects the liquid or gas discharged by the impeller.

WAS WAS

Waste **A**ctivated **S**ludge, mg/*L*. The excess growth of microorganisms which must be removed from the process to keep the biological system in balance.

WASTE ACTIVATED SLUDGE (WAS) WASTE ACTIVATED SLUDGE (WAS)

The excess growth of microorganisms which must be removed from the process to keep the biological system in balance.

WASTEWATER WASTEWATER

The used water and solids from a community that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER HAMMER WATER HAMMER

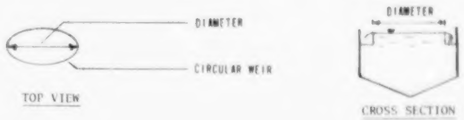
The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

WEIR (weer) WEIR

(1) A wall or plate placed in an open channel and used to measure the flow. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used. (2) A wall or obstruction used to control flow (from clarifiers) to assure uniform flow and avoid short-circuiting.

WEIR DIAMETER (weer) WEIR DIAMETER

Many circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter of the weir is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



WEIR, PROPORTIONAL (weer) WEIR, PROPORTIONAL

A specially shaped weir in which the flow through the weir is directly proportional to the head.

WET OXIDATION WET OXIDATION

A method of treating or conditioning sludge before the water is removed. Compressed air is blown into the liquid sludge. The air and sludge mixture is fed into a pressure vessel where the organic material is stabilized. The stabilized organic material and inert (inorganic) solids are then separated from the pressure vessel effluent by dewatering in lagoons or by mechanical means.

WET WELL WET WELL

A compartment or room in which wastewater is collected. The suction pipe of a pump may be connected to the wet well or a submersible pump may be located in the wet well.

Y, GROWTH RATE Y, GROWTH RATE

An experimentally determined constant to estimate the unit growth rate of bacteria while degrading organic wastes.

ZOOGLEAL FILM (ZOE-glee-al) ZOOGLEAL FILM

A complex population of organisms that form a "slime growth" on the trickling-filter media and break down the organic matter in wastewater. These slimes consist of living organisms feeding on the wastes in wastewater, dead organisms, silt, and other debris. "Slime growth" is a more common word.

ZOOGLEAL MASS (ZOE-glee-al) ZOOGLEAL MASS

Jelly-like masses of bacteria found in both the trickling filter and activated sludge processes. These masses may be formed for or function as the protection against predators and for storage of food supplies. Also see BIOMASS.

SUBJECT INDEX
ADVANCED WASTE TREATMENT

NOTE: All chapter numbers refer to Volumes I and II of *OPERATION OF WASTEWATER TREATMENT PLANTS*

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